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International Library of Technology

A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN ENGINEERING PROFESSIONS, TRADES, AND VOCATIONAL OCCUPATIONS OR FOR THOSE WHO DESIRE INFORMATION CONCERNING THEM. FULLY ILLUSTRATED

GEOMETRICAL DRAWING
MECHANICAL DRAWING
SHIP DRAFTING
SKETCHING
PRACTICAL PROJECTION
DEVELOPMENT OF SURFACES

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PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscripts are prepared by persons thoroughly qualified both technically and by experience to write with authority, and in many cases they are regularly employed elsewhere in practical work as experts. The manuscripts are then carefully edited to make them suitable for correspondence instruction. The Instruction Papers are written clearly and in the simplest language possible, so as to make them readily understood by all students. Necessary technical expressions are clearly explained when introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for more congenial occupations. Usually they are employed and able to devote only a few hours a day to study. Therefore every effort must be made to give them practical and accurate information in clear and concise form and to make this information include all of the essentials but none of the non-essentials. To make the text clear, illustrations are used freely. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title are listed the main topics discussed. At the end of the volume will be found a complete index, so that any subject treated can be quickly found.

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CONTENTS

GEOMETRICAL DRAWING

(PART 1)

PRINCIPLES

INTRODUCTION

1. Drawing is the art of representing objects or ideas on a plane surface, as on a sheet of paper. Drawings are of two classes, according to the plan followed in making them. When drawings are made free hand, that is, without the use of instruments, they are **freehand drawings**; when they are made with the aid of instruments they are **mechanical drawings**, or, as they are sometimes called, *instrumental drawings*. The use of instruments results in greater accuracy than can be secured by the hand alone.

Geometrical drawings are mechanical drawings for which the *positions* of lines must be determined from the principles of geometry. Geometry is the branch of mathematics that treats of space and its relations; it is the science of the relative positions of points, lines, angles, surfaces, and solids. Geometrical processes are based on *reason* independent of measurement, construction, etc. Geometrical principles are *absolutely true*, and if one understands these principles, the correctness of a drawing will depend entirely on accuracy in the use of drawing instruments. **Mensuration** is the branch of mathematics that has to do with finding lengths of lines, areas of surfaces, and volumes of solids.

2. In order that those who have no knowledge of geometry and mensuration can proceed intelligently with the drawing

work, definitions and explanations of such terms and propositions as will be encountered are given in the following pages. These definitions are important and must be thoroughly understood.

DEFINITIONS

LINES

3. A **point** indicates position only; it has no length, breadth, or thickness. It may be represented on paper by a dot.

4. A **line** has one dimension only, namely, *length;* it may be straight, curved, or irregular.

5. If the direction of a line does not change, it is a **straight line,** as in Fig. 1 (*a*); if the direction changes continually about

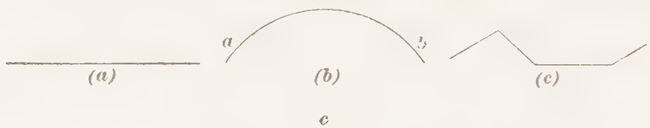


FIG. 1

a point, or center, it is a **curved line,** as in Fig. 1 (*b*), where *a b* is the line and *c* the center from which it was drawn. A line made up of straight lines having different directions, as in Fig. 1 (*c*), is called an **irregular line.**

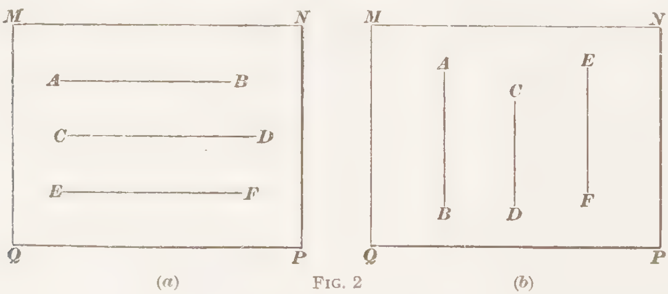


FIG. 2

6. A **horizontal line,** as the term is used in drawing, is a straight line running from left to right, or from right to left, without slanting either upwards or downwards. In Fig. 2 (*a*),

A B, *C D*, *E F* represent horizontal lines on a sheet of drawing paper *M N P Q*. These lines are parallel to the top and bottom edges of the sheet.

7. Vertical lines with reference to the drawing paper *M N P Q*, Fig. 2 (*b*), are the straight lines *A B*, *C D*, *E F* running exactly up and down, without slanting to either the right or the left.

Parallel lines are those that are at an equal distance apart throughout their entire length, as the horizontal lines in Fig. 2 (*a*) and the vertical lines in Fig. 2 (*b*).

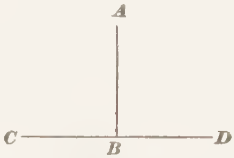


FIG. 3

8. A line is **perpendicular** to another line when it meets it so as not to incline toward it on either side; for example, in Fig. 3, line *A B* is perpendicular to the horizontal line *C D*; however, for a line to be perpendicular to another, it is not necessary that either line should be horizontal or vertical.

FIG. 4

9. Oblique lines are lines that are neither vertical nor horizontal, as in Fig. 4. Such lines are frequently referred to as **inclined lines.**

10. When two lines cross, or cut, each other as in Fig. 4, they are said to **intersect.** The point *A* at which they meet is the **point of intersection.**

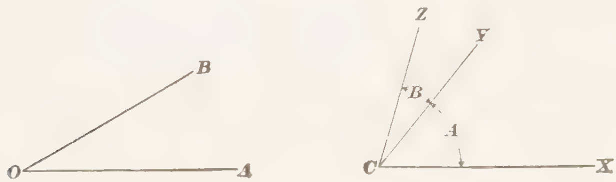
ANGLES

11. An **angle,** Fig. 5 (*a*), is the opening between two straight lines that meet in a point. The two straight lines are the **sides,** and the point where the lines meet is the **vertex** of the angle. Thus, the straight lines *O A* and *O B* form an angle at the point *O*; the lines *O A* and *O B* are the sides of this angle, and the point *O* is its vertex.

An angle is usually referred to by naming a letter on each of its sides and a third letter at the vertex, the letter at the

vertex being placed between the other two. Thus, the angle in Fig. 5 (*a*) is called angle *A O B* or angle *B O A*.

An angle may also be designated by a letter placed between its sides near the vertex. Thus, in Fig. 5 (*b*), the two angles



(*a*) Fig. 5 (*b*)

X C Y and *Y C Z* may be referred to as the angles *A* and *B*, respectively.

An angle that stands alone, that is, an angle whose vertex is not the vertex of any other angle, may be designated by naming the letter at its vertex. For example, the angle in Fig. 5 (*a*) may be called angle *O*.

12. Any angle may be thought of as being formed, or **generated,** by a line turning about the vertex as a pivot, from the position of one side to the position of the other. Thus, the angle *A O B*, Fig. 5 (*a*), may be conceived as generated by a line turning about *O* from the position *O A* to the position *O B*. The size of the angle does not depend on the length of the sides, which are supposed to be of indefinite length, but on the opening between the sides; or, what is the same thing, on the amount of turning necessary to bring one side to the position of the other.

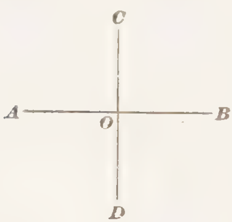


Fig. 6

13. If a straight line intersects another straight line, as *A B* and *C D*, Fig. 6, so that they are perpendicular to each other, the angles formed by the lines are equal. Thus, in the figure, four right angles are formed about the point of intersection *O*, namely, *BOC*, *COA*, *DOA*, and *DOB*. From this it is evident that only four right angles can be formed around a given point.

14. An **oblique angle** is any angle that is not a right angle. Suppose that the line $O\ C$, Fig. 6, is turned about the center O to the position shown in Fig. 7; two oblique angles, $B\ O\ C$ and $A\ O\ C$, will then be formed.

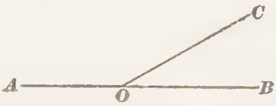


Fig. 7

15. An **acute angle** is one that is less than a right angle. In Fig. 7, angle $B\,O\,C$ is an acute angle. An **obtuse angle** is one that is greater than a right angle; thus, angle $A\,O\,C$, Fig. 7, is an obtuse angle.

PLANE FIGURES

16. A **surface** is the exterior part of anything that has length, breadth, and thickness. A **plane surface** is a flat surface extending uniformly in one direction. A plane surface is often referred to simply as a **plane.** A plane surface has two dimensions only, *length* and *breadth.* The top surface of a body of water or of a table or the surface of the side walls of a room is a plane surface. A **curved surface** is a

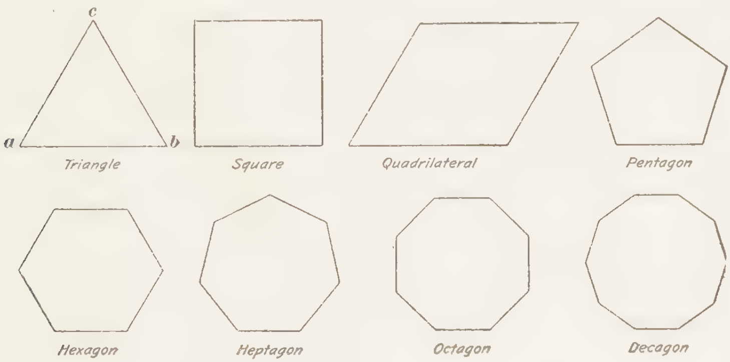


Fig. 8

surface that is bent at all points so that no part is a straight line. The outside surface of a ball is a curved surface.

17. A **plane figure** is a plane surface bounded by lines. Figures bounded by straight lines are called **polygons.** The bounding lines are called **sides.**

Polygons are named according to the number of their sides. A **triangle** has three sides; a **quadrilateral**, four; a **pentagon**, five; a **hexagon**, six; a **heptagon**, seven; an **octagon**, eight; and a **decagon**, ten. These polygons are illustrated in Fig. 8.

A **regular polygon** is one in which all the sides and all the angles are equal. In the triangle shown in Fig. 8, the sides ab, ac, and bc are equal and all the angles are equal; hence, the triangle is a regular polygon.

The **perimeter** of a polygon is the distance around its sides.

TRIANGLES

18. Triangles have three sides and three angles; they are named according to their sides as *isosceles*, *equilateral*, and

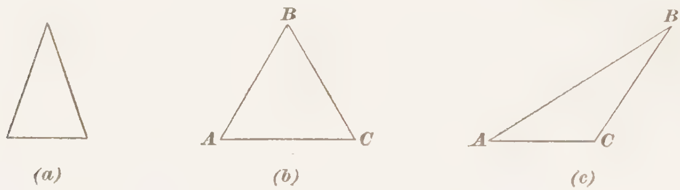


FIG. 9

scalene triangles; and according to their angles, as *right-angled* and *oblique-angled* triangles.

19. An **isosceles triangle,** Fig. 9 (*a*), is one having two of its sides equal. An **equilateral triangle,** Fig. 9 (*b*), is one having all three of its sides equal; it is also an isosceles

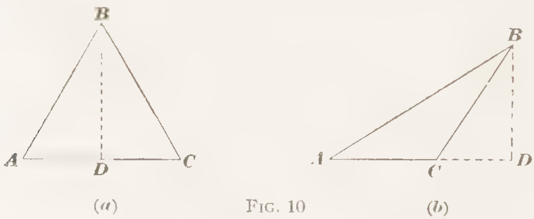


FIG. 10

triangle, because two of its sides are equal. A **scalene, or oblique, triangle,** Fig. 9 (*c*), is one having no right angle.

20. The **base** of any triangle is the side on which the triangle is considered to stand; any side may be considered as the base. In Fig. 9 (*b*) and (*c*), the line *A C* is the base.

21. The **altitude,** or *height*, of a triangle is the vertical distance between the vertex of the angle opposite the base and the base, or the base produced. In Fig. 10 (*a*) and (*b*), *B* is the vertex of the angle formed by intersection of the sides *A B* and *B C*; the side *A C* is the base, and *B D* is the altitude. In (*b*), *A D* is the base produced, or extended.

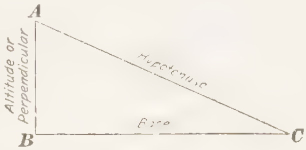


FIG. 11

22. A **right-angled triangle,** or *right triangle*, is a triangle having one right angle. In Fig. 11, the sides *A B* and *B C* form a right angle at *B*. The side opposite the right angle, as *A C*, is the **hypotenuse.**

QUADRILATERALS

23. **Parallelograms** are quadrilaterals whose opposite sides are parallel and opposite angles are equal. There are

FIG. 12

four kinds of parallelograms: the *square*, the *rectangle*, the *rhomboid*, and the *rhombus*, shown, respectively, in Fig. 12.

24. A **diagonal** of any parallelogram is a straight line joining opposite corners, as shown at the left in Figs. 12 and 13.

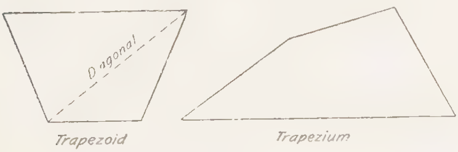


FIG. 13

25. A **quadrilateral** with only two sides parallel is a **trapezoid,** and one with no two sides parallel is called a **trapezium.** These are shown in Fig. 13.

THE CIRCLE

26. A **circle** is a plane figure enclosed by a curved line, called its **circumference**, every point of which is equally distant from a point within called its **center.** In Fig. 14 are shown some of the principal parts of a circle.

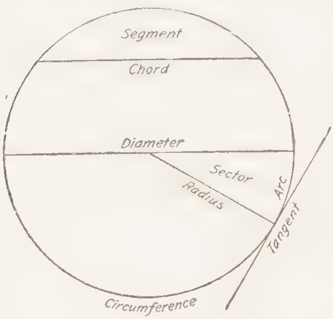


FIG. 14

27. The **diameter** of a circle is a straight line passing through its center and terminated at both ends by the circumference. The **radius** is one-half of the diameter. The plural of radius, that is, the form of the word meaning more than one radius, is **radii.** An **arc** is any part of the circumference. A **chord** is any straight line joining two points in the circumference The part of the circle included between an arc and its chord is called a **segment.** A **sector** is the space between two radii and the arc joining them. If a circle is divided into halves, each half is called a **semicircle** and each arc is called a **semicircumference.** When a circle or its circumference is divided into four equal parts, each part is termed a **quadrant.** A **tangent** to a circle is a straight line that touches the circumference at one point only and stands perpendicular to the radius drawn to that point.

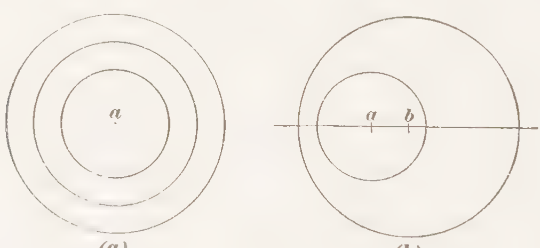
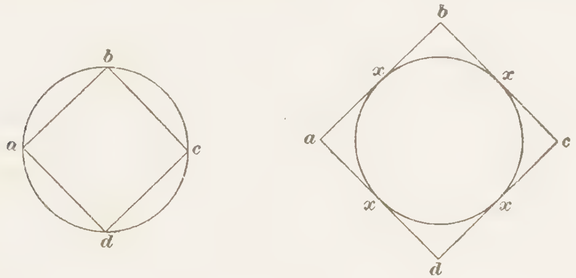


FIG. 15

28. When two or more circles are described from the same center, as a in Fig. 15 (a), they are **concentric.**

Two circles drawn from different centers, as a and b in Fig. 15 (b), are said to be **eccentric.**

29. In the work of geometrical drawing, circles are drawn with compasses, as explained later. Such expressions as



(a) Fig. 16 (b)

describe a circle or *describe an arc* mean that these curves are to be drawn with the compasses. Any polygon drawn within a circle so that its corners lie in the circumference, as $a\,b\,c\,d$, Fig. 16 (a), is said to be **inscribed** within the circle. Any polygon $a\,b\,c\,d$, Fig. 16 (b), drawn on the outside of a circle so that all its sides touch the circumference, as shown at x, is said to be **circumscribed** about the circle. Similarly, a circle may be said to be inscribed in a polygon, as in Fig. 16 (b), or circumscribed about it, as in Fig. 16 (a).

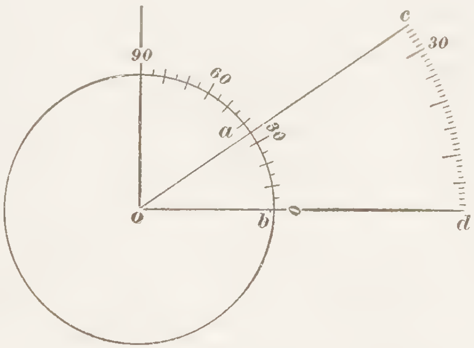


Fig. 17

30. Measuring Angles.—For the purpose of measuring angles, the circumference of a circle is divided into 360 equal parts called **degrees.** A degree is, therefore, $\frac{1}{360}$ of the circumference of a circle; and this is true whether the circle is large or small, as a degree is a proportionate part, not a measure of length.

If, as in Fig. 17, two lines *o c* and *o d* are drawn from the center *o* of a circle and cutting its circumference, the number of degrees on that part of the circumference lying between the two lines is the measure of the angle between the lines.

In Fig. 17, one-fourth of the circle is divided into spaces of 5 degrees each, and it is seen that the arc *a b* included between the lines *o c* and *o d* contains seven of these spaces, or 35 degrees.

As the lines *o c* and *o d* are extended past the points *a* and *b*, the distance between them constantly increases, and when they cut the arc *c d*, which is part of the circumference of a larger circle having the same center *o*, the distance between them is much greater than where they cut the arc *a b*, but it is the same proportionate part of the circumference of the greater circle; that is, $\frac{35}{360}$, or 35 degrees. Therefore, the measure of the angle *c o d* is the same whether measured on the arc of the large or the small circle.

The **measure of any angle** is the number of degrees on the arc included between its two sides, the arc having the vertex of the angle as its center.

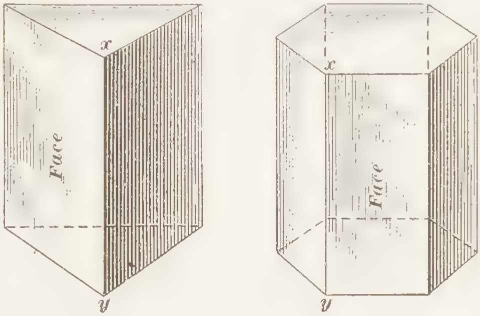
For ordinary drawing work, degree and half-degree divisions give sufficient accuracy of measurement; but for extremely accurate mathematical work degrees are divided into 60ths, which are called minutes, and minutes are divided into 60ths, which are called seconds.

In drawing practice, angles are measured or conveniently laid off by the use of a **protractor**, which is a graduated instrument showing degrees and one-half degrees. This drafting tool will be explained fully further on. The symbol for degrees is °, for minutes is ′, and for seconds is ″; fifteen degrees twenty minutes and thirty seconds may be written 15° 20′ 30″

SOLIDS

31. A **solid** is a body having three dimensions: length, breadth, and thickness. The more common forms of solids met with in engineering and drawing work are **prisms, cylinders, cones, pyramids,** and **spheres.**

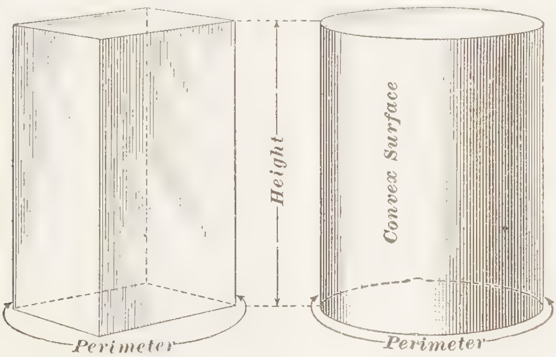
32. Prisms and Cylinders.—A **prism** is a body whose ends are equal parallel polygons and whose sides are parallelograms, as shown in Fig. 18 (*a*) and (*b*). Prisms take their names from the shapes of their bases, or ends. Thus, in Fig. 18 (*a*) the base of the prism is a triangle, and in (*b*) a hexagon, and the prisms are called, respectively, **triangular** and **hexagonal** prisms. The intersections of the sides, or faces, of prisms, as *x y*, are called the edges. A **rectangular** prism is one whose ends are rectangles, as Fig. 19 (*a*). A **cube** is a prism whose ends and faces are square.



(*a*) FIG. 18 (*b*)

A **right prism** is one whose sides are perpendicular to its base, as shown in Fig. 18 and Fig. 19 (*a*). The **entire surface** of a solid is the area of all its sides and ends.

33. A **cylinder** is a round body of uniform diameter with circles for its ends, as shown in Fig. 19 (*b*) The curved surface of a cylinder is called its **convex surface.**



(*a*) FIG. 19 (*b*)

The **altitude, or vertical height,** of a prism or cylinder is the perpendicular distance between its two ends, as indicated in Fig. 19.

The **perimeter** of a prism or a cylinder is the distance around its base.

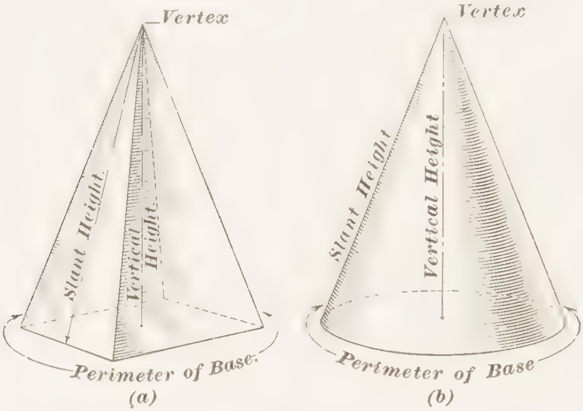


FIG. 20

34. Pyramids and Cones.– A **pyramid** is a solid whose base is a polygon, and whose sides are triangles meeting in a common point, or **vertex,** as shown in Fig. 20 (*a*). A **cone,**

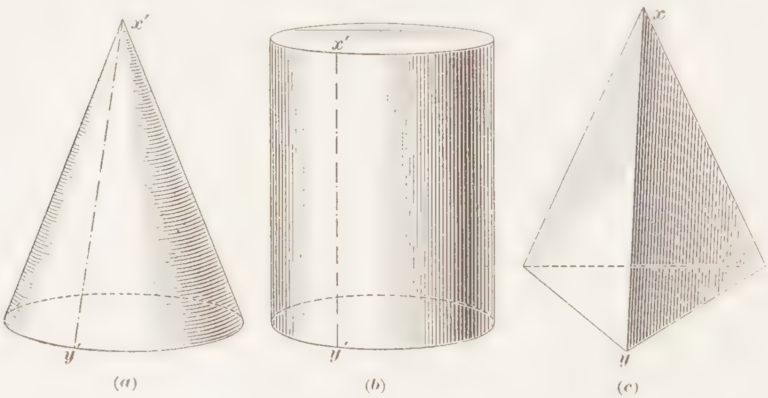


FIG. 21

Fig. 20 (*b*), is a solid with a circular base, and whose convex surface tapers uniformly to a point called the vertex. The

altitude, or vertical height, of a pyramid or a cone is the perpendicular distance from the vertex to the base. The **slant**

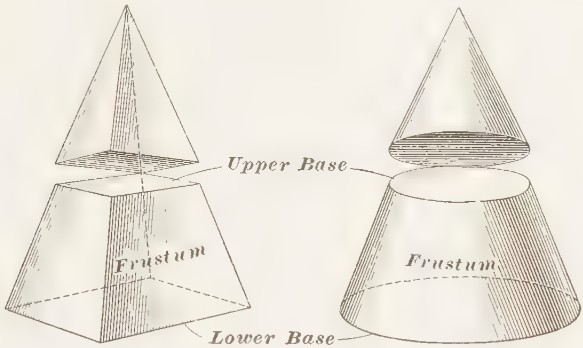


FIG. 22

height of a pyramid is a line drawn from the vertex perpendicular to one of the sides of the base.

The slant height of a cone is measured on a straight line drawn from the vertex to the circumference of the base.

35. In the convex surfaces of cones and cylinders imaginary lines called **elements** are assumed to be drawn. These lines are often referred to in the problems relating to the cone and cylinder. The lines $x' y'$ in Fig. 21 (*a*) and (*b*) are elements. The line $x\,y$ in (*c*) is an intersection line, or edge line, and is not an element.

36. Frustums of Pyramids or Cones.—When a pyramid or a cone is cut by a plane parallel to its base, as in Fig. 22, the lower part is called the **frustum** of the pyramid or the frustum of the cone, as the case may be.

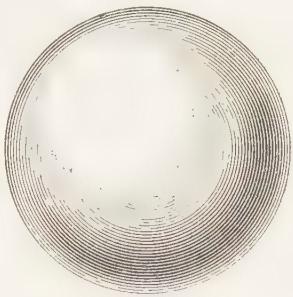


FIG. 23

37. The Sphere.—A **sphere,** Fig. 23, is a solid bounded by a uniformly curved surface, every point of which is equally distant from a point within, called its center. The term **ball** is often used instead of sphere.

DRAWING INSTRUMENTS AND THEIR USE

DRAWING BOARD

38. The drawing board should be made of well-seasoned, straight-grained pine, the grain running lengthwise. To avoid the tendency of the board to warp, the wood of which it is made is thoroughly dried before it is put together. But as wood absorbs moisture from the air, warping will not be avoided if the board is kept near a stove, radiator, or other source of heat. The tendency to warp can be counteracted to a considerable extent by the manner of constructing the board.

A board similar to the one shown in Fig. 24, which is about 21 inches long and 16 inches wide, can be recommended as meeting the requirements of all work in this Section. In the

Fig. 24

making of such a board seasoned pine strips of the number necessary to make the required width of board are glued together. Two hardwood cleats are screwed to the back, to prevent the board from bending or warping, and as a further precaution grooves are cut on the back between the wooden strips in the direction of their length. These grooves reduce the tendency of the board to warp and do not materially affect its longitudinal strength. The cleats also raise the board from the table, thus making it easier to change the board to any required position.

The drawing board should be so arranged that the draftsman can do his work conveniently and to the best advantage.

If no drawing table is used, the best support for the board is a solid table of the form shown in Fig. 25. Usually, when in use, the board is placed so that one of its short edges is at the left of the draftsman and the board is inclined as shown. A block of wood or anything else may be used to tilt the board to the desired angle.

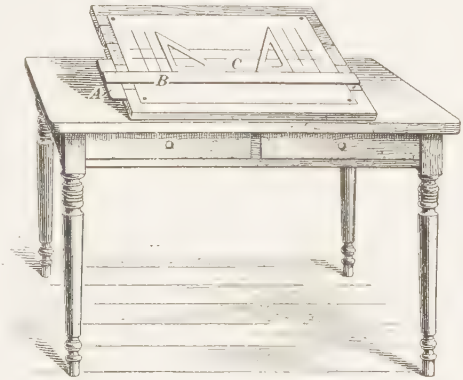


FIG. 25

T SQUARE

39. For drawing horizontal straight lines, the **T square** shown in Fig. 25 is used in the position shown. The head *A* of the T square should be firmly held against the left edge of the drawing board, whether the short or the long side of the board is at the left. The T square must never be used against more than one edge of the board for the same drawing. In some of the geometrical drawing work required, it will be found that the board must be turned with the long side to the left. To draw a horizontal straight line, the blade *B* must be moved so that its edge *C* will be at the place where the line is to be drawn. Any number of parallel straight lines, as shown in Fig. 25, can be drawn by moving the blade the required distance.

DRAWING PAPER

40. The quality of drawing paper recommended for this series of drawing lessons is **cold-pressed demy**, a grade of paper of even grain and rather rough surface. It takes ink well and withstands considerable erasing.

41. Fastening Drawing Paper.—The paper is fastened on the drawing board by means of **thumbtacks**, Fig. 26,

which are small tacks having a sharp point and a large flat head. When fastening a sheet of drawing paper on the drawing board, care must be taken to stretch it evenly, so that it will have no wrinkles. To do this, proceed as follows: Lay the paper on the drawing board with the edges parallel to, and equally distant from, the sides. Insert a thumbtack in the upper right-hand corner, about $\frac{1}{4}$ inch from the edge of the paper, and press it in until the head bears evenly on the paper all around. Line the upper edge of the paper so that it is parallel with the ruling edge of the **T**-square blade. Then pull the paper by sliding the hand lightly and diagonally toward the lower left-hand corner, and, holding the paper there, press in another thumbtack, as before. Lay the left hand on the middle of the sheet, slide it very lightly toward the upper left-hand corner, and insert another tack. The fourth tack is inserted in the same way as the third, except that the left hand is slid from the center to the lower right-hand corner. If the paper is wrinkled or loose, it shows that it has been unevenly stretched, and the preceding operation must be repeated until the sheet lies flat and smooth on the board.

Fig. 26

42. In damp weather the paper usually swells and becomes loose and wavy. In such cases a tack may be put in the middle of each edge of the sheet, after the paper has been gently and evenly smoothed from the center to the middle of each edge. The tacks in the corners are then taken out and reinserted a little to one side of their former positions, after the sheet is evenly stretched toward each corner. By putting the four tacks in the middle of the sides first, the drawing will be kept in the same position on the board. This precaution is very important when a **T** square is used.

DRAWING PENCILS

43. For drawing instrumental problems in pencil, a 4H pencil of any good make should be employed. The use of a pencil softer than this is not recommended, as the point of a soft pencil wears away so fast that accurate work cannot be done, and soft black marks rub off and soil the drawing.

Fig. 27

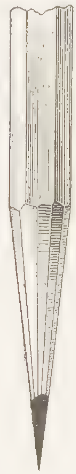


Fig. 28

The pencil should be sharpened as shown in Fig. 27. Cut the wood away so as to leave about $\frac{1}{4}$ or $\frac{3}{8}$ of an inch of the lead projecting; then sharpen it flat by rubbing it against a fine file or a piece of fine emery cloth or sandpaper that has been fastened to a flat stick. Grind it to a sharp edge like a knife blade, and round the corners very slightly, as shown in the figure. If sharpened to a round point, Fig. 28, the lead will wear away very quickly and make broad lines, and unless the pencil is frequently sharpened it is difficult to draw a line exactly through a point.

TRIANGLES

44. Triangles, or set squares, are used for drawing perpendiculars, angles, and parallel lines. The triangles most generally used are shown in Figs. 29 and 30. Each has one right angle, or 90° angle. The triangle shown in Fig. 29 has two angles of 45° each, and that in Fig. 30 one of 60° and one of 30°. They are called *45°* and *60° triangles*, respectively.

To draw a vertical line, place the **T** square in position to draw a horizontal line, and lay the triangle against it, so as to form a right angle. Hold both **T** square and triangle lightly with the left hand, so as to keep them from slipping, and draw the line with the pen or pencil held in the right hand, and against the

edge of the triangle. Fig. 31 shows the triangles and **T** square in position.

45. To draw parallel lines that are neither vertical nor horizontal.

When the lines are near together, the best way is to place one edge of a triangle, as *a b*, Fig. 32, on the given line *c d*,

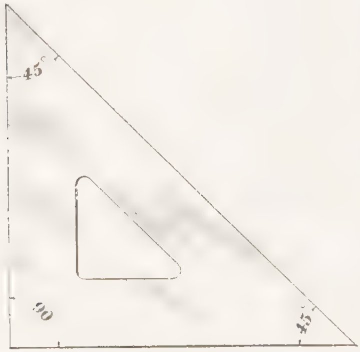


Fig. 29

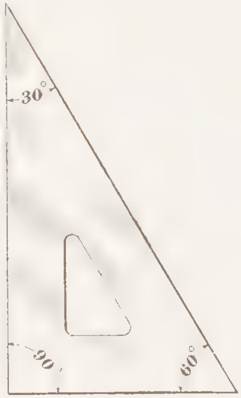


Fig. 30

and lay the other triangle, as *B*, against one of the two edges, holding it fast by letting the left hand rest on it; then move the triangle *A* along the edge of *B*. The edge *a b* will remain parallel to the line *c d*; and when the edge *a b* reaches a point, as *g*, through which it is desired to draw the parallel line, hold both triangles stationary with the left hand and draw the line *e f* by passing the pencil along the edge *a b*. Should the triangle *A* extend so far beyond the edge of the triangle *B* that the desired position cannot be reached, hold *A* stationary with the left hand and shift *B* along the edge of *A* with the right hand and then proceed as before.

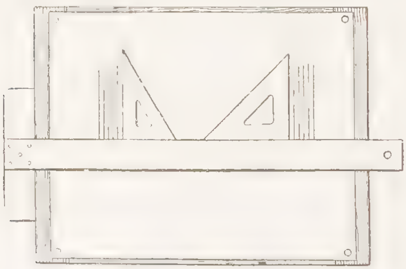


Fig. 31

46. To draw a line at right angles to another line which is neither vertical nor horizontal.

Let *c d*, Fig. 33, be the given line (shown at the left-hand

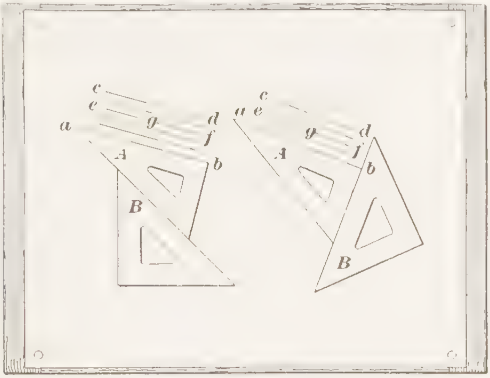


Fig. 32

side). Place one of the shorter edges, as *a b*, of the triangle *B* so that it will coincide with the line *c d*; then, keeping the tri-

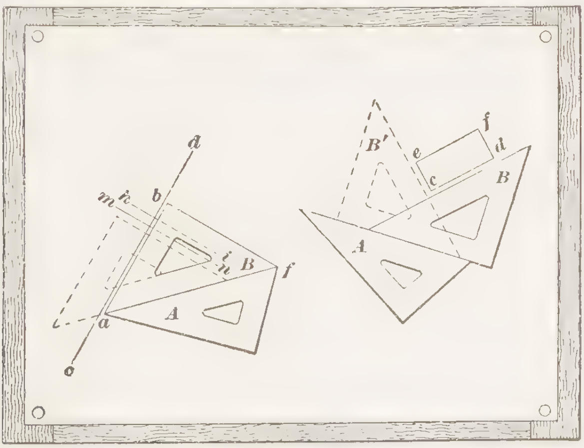


Fig. 33

angle in this position, place the triangle *A* so that its long edge will come against the long edge of *B*. Now, holding *A* securely in place with the left hand, slide *B* along the edge of *A* with

the right hand, and draw the lines *h i*, *m n*, etc. perpendicular to *c d* along the edge *b f* of the triangle *B*. The dotted lines show the position of the triangle *B* when moved along the edge of *A*.

47. The right-hand portion of Fig. 33 shows another method of accomplishing the same result, and illustrates how the triangles may be used for drawing a rectangular figure when the sides of the figure make an angle with the **T** square such that the latter cannot be used.

Let the side *c d* of the figure be given. Place the *long* side of the triangle *B* so as to coincide with the line *c d*, and bring the triangle *A* into position against the lower side of *B*, as shown. Now, holding the triangle *A* in place with the left hand, revolve *B* so that its other short edge will rest against the long edge of *A*, as shown in the dotted position at *B′*. The parallel lines *c e* and *d f* may now be drawn through the points *c* and *d* by sliding the triangle *B* on the triangle *A*, as described in connection with Fig. 32. Measure off the required width of the figure on the line *c e*, reverse the triangle *B* again to its original position, still holding the triangle *A* in a fixed position with the left hand, and slide *B* on *A* until the long edge of *B* passes through *e*. Draw the line *e f* through the point *e*, and *e f* will be parallel to *c d*. It is advisable to practice drawing lines that are parallel and perpendicular to each other with the triangles before beginning the drawing lessons that follow.

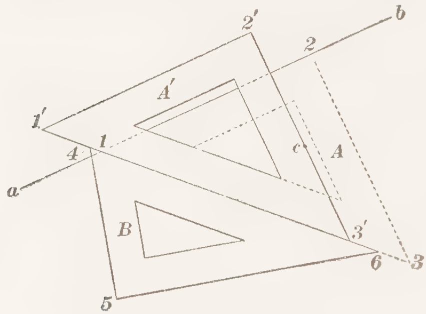


Fig. 34

48. To draw, by means of the triangles, a perpendicular to a line through a given point.

In Fig. 34, *a b* is the given line to which it is required to draw a perpendicular through the point *c*. Place one triangle, as *A*, so that one leg, as *1–2*, lies on the given line, while

the other leg, as *2–3*, is a little to one side of the given point *c*, as shown by the dotted triangle. Place the other triangle *B* along the hypotenuse *1–3* of triangle *A*, as shown by the triangle *4–5–6*. Now slide the triangle *A* along the side of *B* until the leg *2–3* lies on the point through which the perpendicular is to be drawn, as shown by the triangle *1′–2′–3′*. A line drawn with the leg *2′–3′* as a ruling edge will be the required perpendicular.

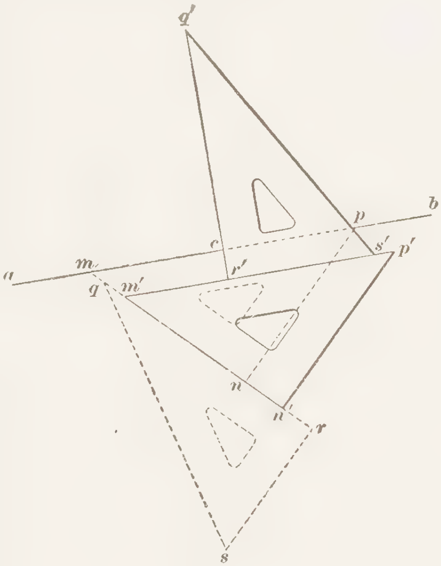


FIG. 35

49. A method that can be used when it is desired to draw a longer line than can be made by the preceding method is as follows:

Let *a b*, Fig. 35, be the given line, and *c* the given point, which, in this problem, lies on the line. First, place one triangle *m p n* so that the hypotenuse *m p* will coincide with the line. Place one edge of the other triangle *q r s* along *m n*, as shown. Hold triangle *q r s* firmly in place and slide triangle *m n p* along *q r* a short distance, until it takes the position *m′ n′ p′*. Hold *m′ n′ p′* firmly, and take the other triangle *q r s* and put it in the position *q′ r′ s′*, with the short side in contact with *m′ p′*. A line drawn along *q′ r′* will be perpendicular to *a b*, and, by sliding triangle *q′ r′ s′* along *m′ p′*, the edge *q′ r′* may be made to pass through any required point.

50. To draw, by means of the triangles, lines making angles of 30°, 45°, or 60° with a given line.

There are several ways of doing this, all similar to those used for the drawing of perpendiculars. The following is one of the convenient methods:

Let $a\,b$, Fig. 36, be the line with which the required line is to make an angle of 30°. Place the 45° triangle so that one of its edges (preferably the hypotenuse) will coincide with $a\,b$, and then slide it down along the edge of the other triangle until it takes the position $m\,n\,p$. Holding it firmly in this position, place the other triangle as shown by $q'\,r'\,s'$, that is, with the vertex of the right angle and that of the 30° angle against $m\,n$. By sliding $q'\,r'\,s'$ along $m\,n$, it is possible to make $q'\,s'$ pass through any required point. Any line drawn along $q'\,s'$, in any of the positions of triangle $q'\,r'\,s'$, will make an angle of 30° with $a\,b$. If it is desired to have the angle opening toward

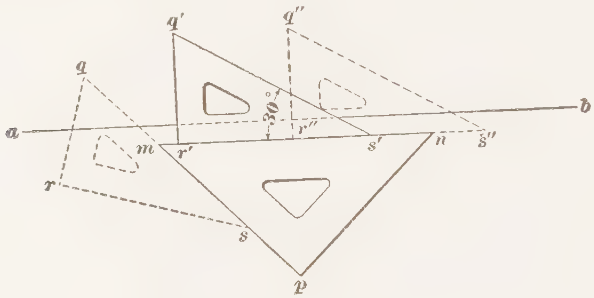


FIG. 36

the right, triangle $q'\,r'\,s'$ must be turned over about $q'\,r'$; in other words, it should be so placed on $m\,n$ that r' will be at the right of s'.

An angle of 60° may be drawn in a similar manner by placing the triangle $q'\,r'\,s'$ so that r' and q' will be on $m\,n$. The method of drawing a 45° angle is the same, but in this case the 60° triangle will have to be used in the position $m\,n\,p$, and the 45° triangle in the position $q'\,r'\,s'$.

In using triangles, it is advisable not to allow one to extend more than half its length beyond the other, otherwise there will not be sufficient bearing surface and there will be a tendency for the triangles to rock, thereby making the work inaccurate.

51. To divide the circumference of a circle into two, four, or eight equal parts.

Any straight line, as $a\,b$, Fig. 37, drawn through the center o of a circle, will divide the circumference into halves. Another

line, as *c d*, drawn perpendicular to the first, will divide the circumference into fourths. Two other lines, as *g h* and *e f*, drawn through the center at an angle of 45° with *a b*, will divide the circumference into eighths. Each of the arcs *a g*, *g c*, etc. will be one-eighth of the circumference.

52. To divide the circumference of a circle into six equal parts.

There are two methods:

The first method is to open the dividers equal to the radius of the circle and, beginning at any point on the circumference, step off the chord distances, as *a e*, *e c*, etc., Fig. 38.

The second method is to draw a line, as *a b*, Fig. 38, through the center *o* of the circle, and then, with a 60° triangle, draw

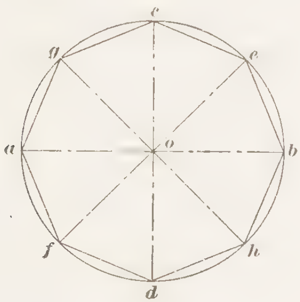


Fig. 37

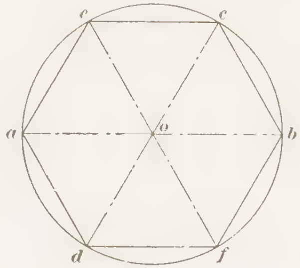


Fig. 38

lines *c d* and *e f*. These lines will intersect the circumference and divide it into six equal parts.

53. Regular inscribed polygons are constructed by joining the points of division of an equally divided circle. Thus, Fig. 37 is a regular inscribed octagon, and Fig. 38 is a regular inscribed hexagon. To inscribe a regular polygon of any number of sides in a given circle, it is only necessary to divide the circumference of the circle into the required number of parts and join the points of division.

54. To draw, with triangles, any angle that is the sum or the difference, or a combination of sums and differences, of the angles 90°, 60°, 45°, and 30°.

Certain angles may be laid off directly with the triangles, either singly or in combination. For example, if a line *a c*, Fig. 39, is to be drawn at an angle of 30° with *f b*, it may be laid off with the triangle shown in Fig. 30. If an angle *b a d* of 75° is to be drawn from the point *a* on the line *a b*, it may be laid off by a combination of the triangles shown in Figs. 29 and 30. Similarly, by drawing the line *a e* at an angle of 60° with the angle *b a d*, an angle of 135° will be obtained.

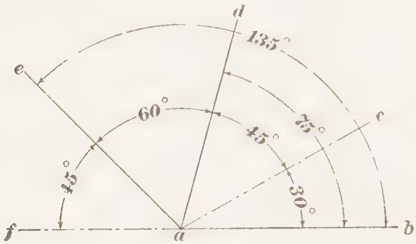


FIG. 39

When the required angle is greater than 90°, it is more easily constructed by laying off an angle that is the difference between the required angle and 180°. Thus, in the preceding example, 45° is the difference between the required angle of 135° and 180°. By laying off the line *a c* at an angle of 45° with *a*, an angle of 135° will be obtained.

PROTRACTOR

55. A **protractor** is a semicircular instrument used for laying off or measuring degrees when triangles cannot be used. It is made of celluloid or metal and is usually graduated to half degrees. The graduations are numbered from each side up to 180, the number of degrees in a half circle, for convenience in laying off degrees on either the right or the left. A protractor with 360 divisions, representing half degrees, is shown in Fig. 40. In laying off angles, the protractor must be placed so that the line *A B* coincides with the line forming one side of the angle and the center *O* is at the vertex of the angle.

For example, let it be required to draw a line making an angle of 54° with the line *O B*, Fig. 41. In this illustration the half-degree divisions are omitted for the purpose of showing the full-degree divisions more clearly. Place the protractor on the

line $O B$, with the center at O. With a sharp-pointed pencil make a mark on the paper at the 54° division, as indicated

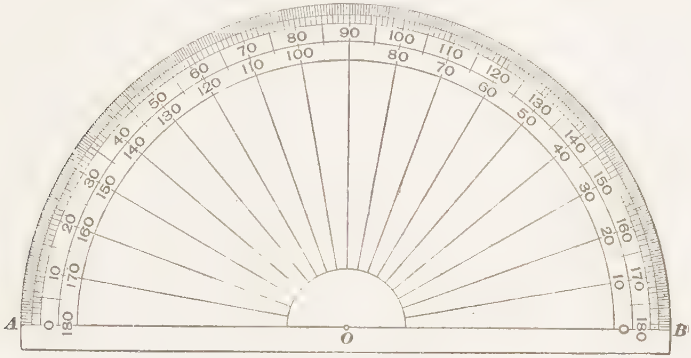


Fig. 40

at C, and draw a line passing through O and C. This line will make an angle of 54° with $O B$. Greater exactness will be

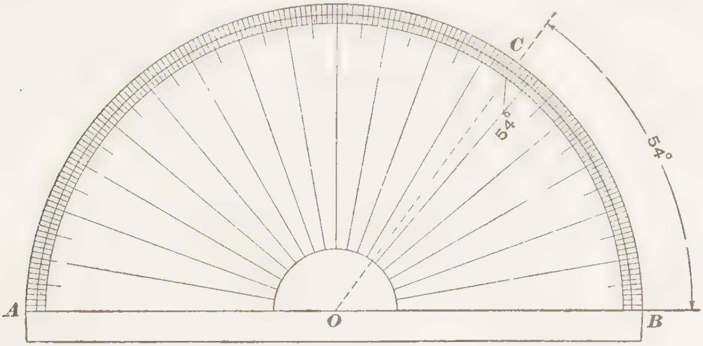


Fig. 41

secured by producing the base line $O B$ to the left so that the zero mark on each end of the protractor will rest on it.

COMPASSES

56. The **compasses** are an instrument used for taking or marking measurements, subdividing distances, describing curves, etc. The compasses, next to the T square and the triangles, are used more than any other instrument.

A common form of compasses is shown in Fig. 42. They consist of two legs joined at the top by means of a fork-shaped brace and held together by means of a screw. The fork carries a head for convenience in handling the instrument and both legs are hinged so that the points may be made to stand in a vertical position, which is necessary in drawing circles. The leg *a* is provided with a socket in which either the pencil point or the pen point *b* shown separately at the right may be inserted. The other leg is also provided with a socket for holding the needle point *c*. In all good instruments, the needle point is adjustable and consists of a round piece of steel of tapering form and having a sharp point. The lengthening bar *d* shown separately is used to extend the leg of the instrument when circles of large radii are to be drawn. The point *e* shown at the upper right-hand side of the illustration is sometimes furnished with compasses so that they can be used as dividers. The point is inserted in the leg *a* instead of the pencil point.

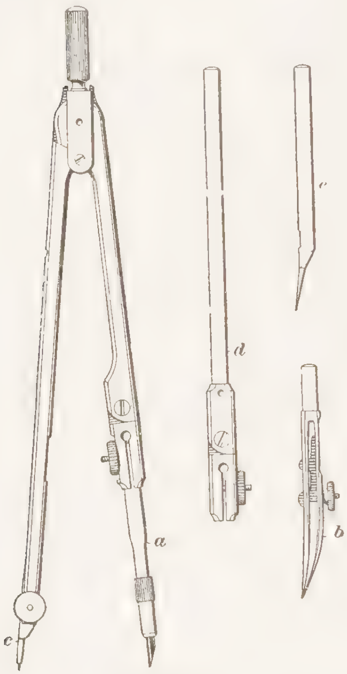


FIG. 42

57. Use of Compasses.—The following suggestions for handling the compasses should be carefully observed by persons

who are beginning to learn how to use them. A draftsman who handles his instruments awkwardly will create a bad impression, no matter how good a workman he may be. The tendency of beginners is to use both hands for operating the compasses. This should be avoided. The student should learn at the start to open and close them with one hand. To do this the needle-point leg should be held between the third and fourth fingers and the thumb and the other leg held between the first and second fingers, as shown in Fig. 43. With the compasses held in this position, they are inclined sidewise until the side of the hand rests on the paper. This steadies the hand so that the needle point of the instrument may be brought to exactly the desired point. When this has been accomplished the instrument is brought to an erect position, and the leg holding the pencil point is moved to the desired radius by the fingers between which it is held, after which the instrument is held by the head and operated as shown in Fig. 44.

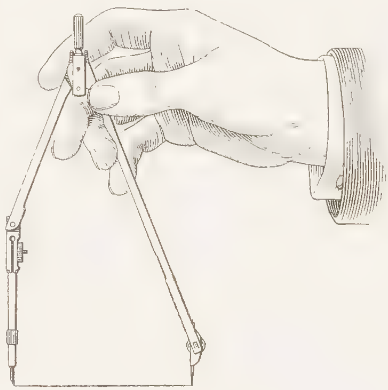


FIG. 43

The compasses must be handled in such a manner that the needle point will not make a large hole in the paper; for this reason use the needle point having a shoulder. In operating the instrument *do not bear on the needle point* and keep it perpendicular to the paper, as shown in Fig. 44. A slight pressure on the pencil point is necessary. The point of the pencil should be sharpened like the one shown in Fig. 27, but its width should be narrower. *It is important that the pencil point be securely fastened.* If the pencil point is loose it will wabble and the curve will not be made with the same radius at all points. This can be tested by striking arcs of circles in both directions. If the pencil point is properly fixed in position the lines will coincide.

58. Dividers.—Although compasses may be used for laying off distances on a drawing or for dividing lines into equal parts, the dividers can be more conveniently used for these purposes. The common form of dividers is shown in Fig. 45. Dividers are adjusted and then held by the head between the thumb and forefinger the same as the compasses. In stepping off distances, the instrument is turned alternately to the right and the left. If on stepping off equal spaces on a line, it is found that the last space is not of exactly the same length as the first, the instrument must be adjusted, and this procedure must be repeated until the last space is of the same length as those preceding. In making these trial spacings, great care must be exercised not to press the divider points into the paper. If the divider points are pressed into the paper, the spacing cannot be done accurately.

FIG. 44

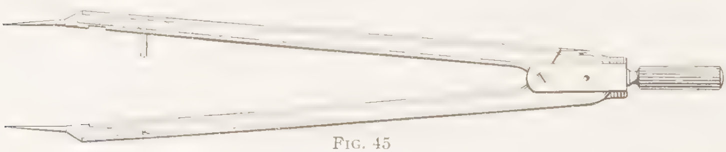


FIG. 45

59. Bow-Pencil and Bow-Pen.—The bow-pencil and bow-pen, shown respectively in Figs. 46 and 47, are small forms of compasses convenient for describing small circles.

Ordinarily the points of the instruments must be adjusted so that both legs are of the same length; but when very small circles are to be drawn, the needle point must be slightly the longer, so that when the point is in the paper the part of the leg above the paper is of the same length as the other leg, otherwise an exact circle cannot be drawn.

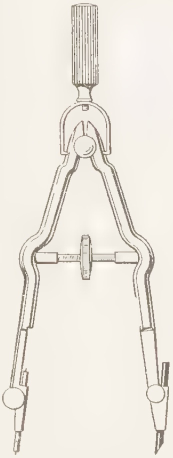


FIG. 16

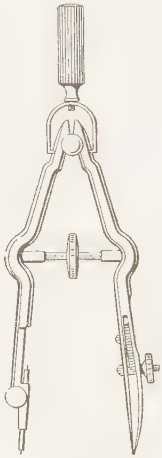


FIG. 17

To draw a circle of a given diameter, the instrument is adjusted approximately to the required radius. It is then placed in an upright position with the point resting on the paper and held by the forefinger pressing lightly on its head. The finer adjustment is then made by turning the adjusting screw with the thumb and the middle finger of the same hand.

60. Use of the Lengthening Bar.—When large circles are to be described, the lengthening bar *d* shown in connection with Fig. 42 must be used. The method of drawing circles by

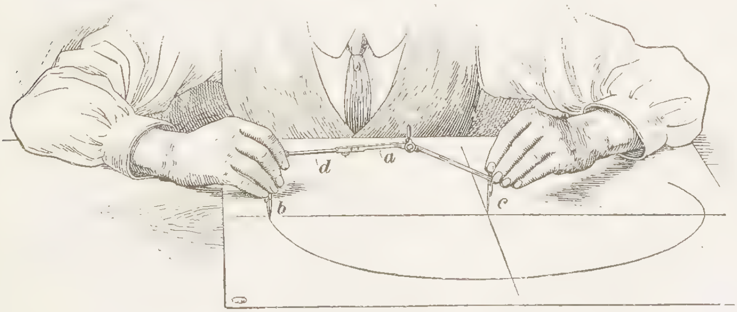


FIG. 48

the use of the lengthening bar is shown in Fig. 48. The lengthening bar is inserted in the socket of the upper part of the leg *a*

and the pen or pencil point is inserted in the socket at the lower end of the lengthening bar. In drawing circles when the lengthening bar is used, the pen point b and the needle point c are held vertical to the plane of the paper, as shown in the illustration. In such cases the instrument is operated with both hands, as shown.

61. Beam compasses are used for describing circles of very large radii. The instrument consists of a beam a, Fig. 49, along which the two pieces b and c slide; these pieces are provided with clamp screws by which they can be fixed on the beam. The piece b carries a needle point, and at c either a pencil holder or a pen may be inserted. By fixing b and sliding c along the beam, the instrument may be set to any radius. Such a compass is not needed in the geometrical drawing work to follow.

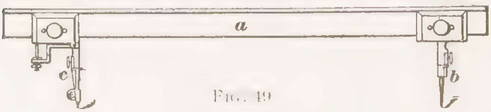


FIG. 49

DRAWING INK AND PENS

62. Drawing Ink.—The ink recommended for drawing work is waterproof liquid India ink. A quill is attached to the cork of every bottle of this ink, by means of which the pen may be filled. The quill is dipped into the ink and the end then passed between the blades of the drawing pen. Not more ink than will fill the blades for a quarter of an inch along their length should be used; if too much is used, the ink is liable to drop and cause blots. The cork should be replaced in the bottle each time the pen is filled.

Before drawing ink is used, the bottle should be well shaken, because some of the ingredients of the ink settle to the bottom, and if the ink is not well mixed the lines will appear gray. If ink becomes too thick it may be diluted by adding a solution composed of 1 ounce of water and 4 drops of aqua ammonia until the ink is of the proper consistency again. Pure water alone should not be used to dilute ink. India ink that has been

frozen cannot be used, as the lines will be very gray and indistinct. The ink bottle should always be kept tightly corked when it is not in use.

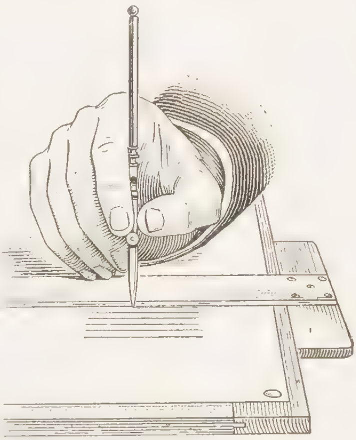


Fig. 50

India ink dries quickly on a drawing, which is desirable, but it also dries quickly on the blades of the pen, which is not desirable, because it prevents the ink from flowing freely, especially when the pen is adjusted for fine lines. The only remedy is to wipe between the blades frequently with a cloth. The blades should always be wiped out before the pen is laid down for any length of time. If the ink does not flow well, it may be started by moistening the end of the finger and touching it to the point or by drawing a slip of paper between the points of the blades.

63. Ruling Pen. For drawing ink lines other than arcs of circles, the ruling pen shown in Fig. 50 is used. The width of line drawn and the flow of ink are controlled by a small screw, which adjusts the distance between the blades. The proper adjustment of the blades is shown in Fig. 51 (*a*) and the improper adjustment in (*b*). It will be noticed that in (*a*) there is a greater volume of ink at the point of the nibs, which is a good feature, as the ink does not dry as fast as when there is a thin film at the points. If the nibs are brought very close together as shown in (*b*), the points are spread so that they stand apart as shown in the illustration and are, therefore, liable to be injured, the flow of ink is retarded, and ragged, gray lines of irregular thickness will be formed.

(*a*) (*b*)

Fig. 51

When drawing pens become dull, the best plan is to send them to the dealer to be sharpened. The sharpening of pens is highly expert work, and dealers are generally willing to do it at a reasonable price.

64. The ruling pen should be held as nearly perpendicular to the board as possible; the hand should be in the position shown in Figs. 50 and 52 and should press the pen only lightly against the edge of the T square or triangle. If the pen is pressed hard against the edge, the blades will close, with the result that uneven lines will be made. The edge of the T square or triangle should serve simply as a guide for the pen. It will be found that considerable practice is required to make smooth lines. If the pen is held so that only one blade bears on the surface of the paper, the line will almost invariably be ragged on the edge on which the blade does not touch. When the pen is held at right angles to the paper, as shown in Fig. 52, both blades will rest on the paper and if the pen is in good condition smooth lines will result.

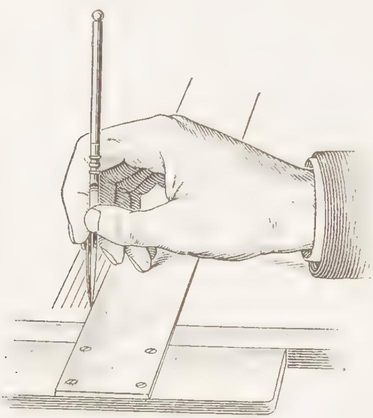


Fig. 52

In some ruling pens a needle point is attached to the head, which can be unscrewed. This needle point is intended for use in pricking holes through a sheet of paper into an underlying sheet on which lines are to be copied.

The ruling pen should always be kept clean. If lint or dust collects on the nibs thick lines or blots will result. Dust that may have accumulated on the drawing paper should be brushed off before lines are drawn.

65. Practice in the Use of Inking-In Instruments. In geometrical drawing great accuracy is required, and only by considerable practice in the use of inking-in instruments

can proficiency be acquired. The beginner should, for drill, draw with ruling pen and ink compasses on good paper lines of different kinds. The practice work should consist of straight lines of different thicknesses and lengths and in different positions, dotted lines (lines made up of a series of short dashes), horizontal and vertical lines that intersect but do not cross, circles and arcs of circles, straight lines tangent to arcs and circles, etc.

CLEANING DRAWINGS

66. A drawing is almost sure to become soiled from the rubbing of the draftsman's sleeves and from dust. This may be prevented to some extent by covering the work, except the part on which work is being done, with paper thoroughly secured at the edges so as not to interfere with the operation of the triangles and **T** square. One of the most frequent causes of dirt on a drawing is the sliding of the instruments over the

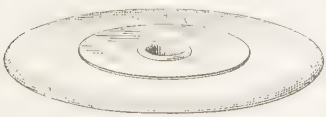


FIG. 53

FIG. 54

surface. Celluloid and rubber triangles are especially apt to accumulate dirt, which is transferred to the drawing when these instruments are moved over the paper. It is considered good practice, before commencing a drawing, to clean carefully the scales, triangles, and **T** square. The drawing board should be dusted before the drawing paper is tacked in place on it, as particles under the drawing paper raise small hills that interfere with the drawing of lines.

After a drawing has been inked in, all soiled spots and pencil lines should be removed with a soft-rubber eraser. This will not injure the ink lines. Before applying the rubber to the drawing, it is a good plan to test it by rubbing it on another sheet of paper to remove any dirt that may adhere to it. If an inked-in line or an ink blot is to be removed, a hard eraser made of a mixture of rubber and emery or glass, such as that

Fig. 55

shown in Fig. 53, should be used. An eraser of this kind cuts away the outer layer of the paper and thus removes the ink lines or blots. It is a good plan, when ink lines are to be removed, to use a celluloid shield such as that shown in Fig. 54. This contains holes of different shapes, so that it is possible to erase particular spots without touching and thus injuring other parts of the drawing. Shields made from thick drawing paper or thin cardboard are also used and have the advantage that slots or holes of the exact shape and size of the spots to be removed may be cut into them; on the other hand, they wear away sooner than those made of celluloid.

SCALES

67. Scales are used for laying off dimensions on drawings. The scales that are usually used are triangular in shape as shown in Fig. 55 or flat with beveled edges. The edges of the triangular scale are graduated for different scales, but as in the geometrical drawing work only the full-size scale is to be used, only this scale will be considered here. The full-size scale is divided, like the ordinary foot rule, into twelve equal parts, called inches, and the inches are subdivided into halves, fourths, eighths, and sixteenths. In using the full-size scale, if it is desired to lay off a dimension as small as a 32d of an inch, it may be done by laying off by eye a point midway between the sixteenth-inch divisions as shown at the left in Fig. 56, in which the subdivisions of the inch are indicated. Dimensions as small as 64ths of an inch may be laid off by eye in the same way by laying off points midway between the 32d-inch divisions. A dimension of $\frac{7}{8}$ inch may be measured by taking seven of the $\frac{1}{8}$-inch divisions, and a dimension of $\frac{5}{16}$ inch may be measured by taking five of the $\frac{1}{16}$-inch divisions, etc.

IRREGULAR CURVE

68. An instrument known as the **irregular curve,** or *French curve,* is used for drawing lines of irregular curvature.

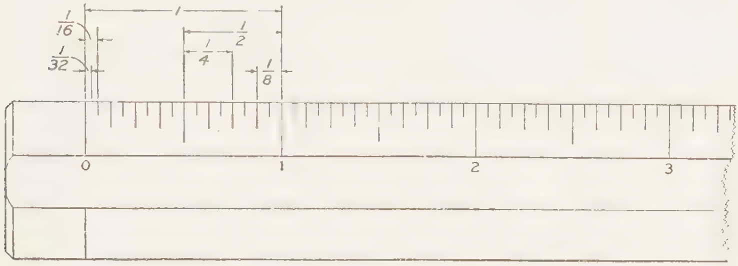


Fig. 56

This instrument is shown in Fig. 57, and its edges have different curvatures at different parts. To draw a line of irregular curvature, the points through which the line is to be drawn must first be determined, and then the curve is placed so that some part of its edge will pass through several of the points determined, then the instrument is shifted as required. Good judgment is required to select the part of the instrument that will give the right curvature and a smooth connection with the part of the line previously made. The curve on the edge of the instrument should be made to pass through at least three of the required points, and if it can be made to pass through a greater number, so much the better, as the fewer the number of parts to be drawn the less liability there will be of getting a line of wavy appearance. Considerable skill is required to

Fig. 57

make curves of irregular shape with a continuous smooth line. It is an advantage to first draw the line in pencil and then ink it in.

To illustrate the use of the irregular curve, let it be required to draw a curved line through the points *a*, *b*, *c*, *d*, etc., Fig. 58. As already said, the curved edge of some part of the instrument should pass through at least three points. By placing the instrument in the first position *A* outlined by dotted lines, the edge is found to pass through five points, *a*, *b*, *c*, *d*, and *e*, and the curved line is drawn through these points, as shown by the full line. To draw the next part of the curve *e f g*, the instrument is shifted to the position *B* and is so adjusted that it will coincide with a part of the curve already drawn and there will be no angle formed where the two parts of the curve join.

In the same way, by shifting the instrument and finding other curves on its edge that will pass through a number of points, the

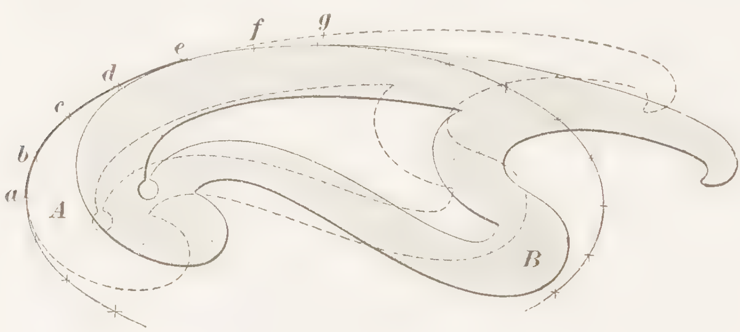


Fig. 58

curved line can be completed. Care should be taken to avoid making sharp angles between connecting sections of the line.

To prevent ink from getting on the edge of the irregular curve and spreading on the drawing, and to make a good line, the blades of the pen must be kept tangent to the edge of the curve; that is, the blade must rest against the edge of the curve tangent to the curved line and must be kept in this position as the pen is moved along the curve. As a precaution against making blots on the drawing, it is advisable to place two thicknesses of paper under the ruler to raise it slightly above the surface of the paper. In this way, if ink should get on the edge of the ruler it will not cause a blot on the drawing.

LETTERING

GENERAL REMARKS

69. On drawings, the headings, explanations, and dimensions are lettered with the pen; script writing is not permissible. Two general styles of lettering are employed on drawings; namely, **single-stroke letters,** which are of two kinds, *slanting* and *vertical*, and **block letters.** Single-stroke letters are adapted for drawings containing many dimensions or on which the space for lettering is limited, as the letters of this form can be condensed without materially affecting their legibility. What is meant by condensing letters is illustrated in Fig. 59, which shows three widths of the same form of letter. The

Fig. 59

slant style is the most natural, as the strokes approximate the direction of the strokes in ordinary writing. Block letters are generally used for main titles and subtitles. It is the usual practice in drawing rooms to adopt a style of letter that is simple in form, legible, and can be made quickly, and all draftsmen in the office are expected to conform to this style. Only the styles of letters in common use, as mentioned preceding, will be discussed here.

For lettering, any good fine-line pen may be used. Gillott's No. 303 pen can be recommended for this purpose. It is possible to make a more uniform line with a pen after it has been used for a short time than when it is new. Waterproof ink dries quickly and for this reason the point should be wiped frequently. A cloth free from lint should be used for this purpose, as the lint would get between the nibs of the pen and clog it.

70. Spacing of Letters.—Next in importance to well-formed letters is the correct spacing of letters in words. By correct spacing is meant the placing of letters at such distances apart as to give the appearance of equal spacing between all letters. The shapes of letters vary, some having slanting sides, some straight sides, and some rounding sides, and others have projecting stems, so that only very general instructions can be given for spacing. Good judgment must be used for this. The letters of a word must be spaced so that the word will have an even appearance and there will be no unduly large white space or dark spot at any point.

More space is required between two letters both of which have straight sides than between two letters one of which has a straight side and one a round side. Less space is required between two letters with rounding sides, as *O O* or *D O*, than is required in either of the preceding cases. The space at the bottom between the two capital letters *A L* should be small so that the space between them at the top will be reduced to the minimum. The capital letters *A W* have parallel sides, consequently considerable space is required between them. The letters that cause the most trouble in spacing are *A*, *W*, *V*, *X*, and *Y*, as, unless good judgment is used, their slanting sides produce unequal white spaces. Letters with projecting strokes, as *F*, *J*, *L*, and *T*, are difficult at times to combine with other letters. The letters that are most easily spaced are those with straight sides, as *H*, *B*, *N*, *D*, etc.

In many drafting rooms a piece of white paper on which horizontal lines are ruled in ink is slipped under the tracing cloth to serve as a guide for lettering. Until one is well trained in lettering, the guide lines should be used; with practice it is possible to make good freehand lettering by using only a base line as a guide

SINGLE-STROKE LETTERING

SINGLE-STROKE SLANT LETTERING

71. Single-stroke slant letters of the size to be used in this drawing work are illustrated in Fig. 60. The same form of letter is shown on an exaggerated scale in Fig. 61 to indicate more clearly the method of forming the letters and the direction in which the strokes are to be made. The direction of the strokes is indicated by small arrows and the order in which they are made is shown by numerals. To produce well-formed and neat-appearing letters, the direction and order of the strokes as given should be observed.

72. Three elements enter into the construction of this form of letters. These are the straight line, the loop, and the hook, as shown in Fig. 62 (*a*), or modifications of the loop and

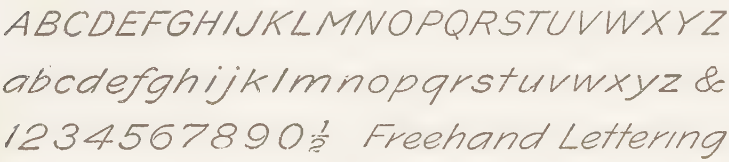


FIG. 60

hook. As will be seen by referring to (*b*), the loop is the main element in the letters *a*, *b*, *d*, *g*, *p*, and *q*, and modifications of it enter into the construction of the *c*, *e*, and *o*. In the letters *a*, *d*, *g*, and *q* the point of the loop is at the top, and in the letters *b* and *p* the point of the loop is reversed. The hook with the turn at the top is used in forming *h*, *m*, and *n*, and the reversed hook is used in *u*. The only difficulty that will be experienced in making the letters *v*, *x*, and *y*, both lower case and capitals, is to draw the sides of the letters at the proper angle. These letters will be well formed if the sides of the *v* and of the *v* part of the *x* and *y* are drawn so that the upper extremities are equally distant from an assumed center line at the angle to which the letters are made, as shown in Fig. 62 (*b*).

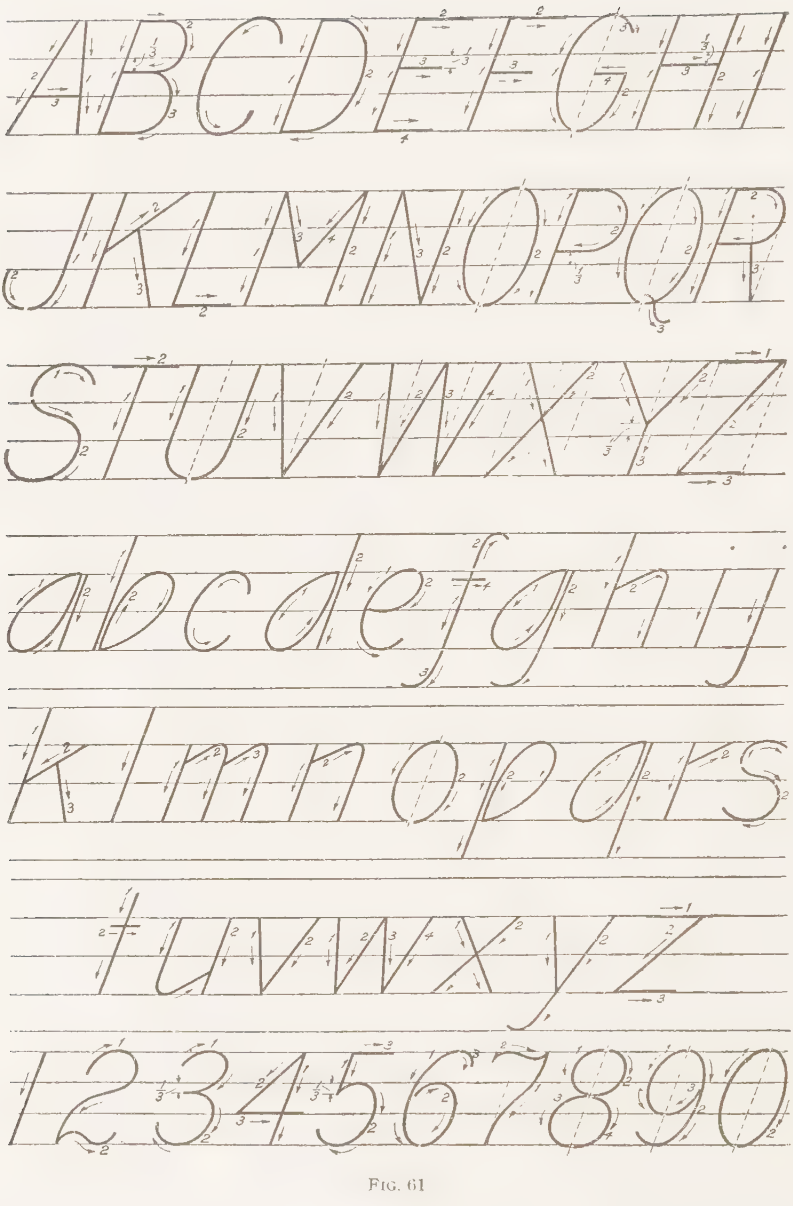


Fig. 61

73. Until the student becomes proficient in drawing the lines of letters at a uniform slant, a templet of the slant used

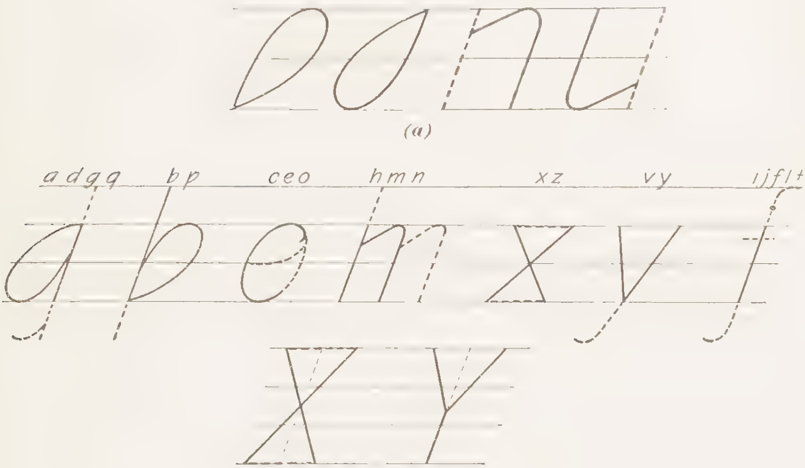


FIG. 62

in the preceding illustrations may be used for drawing guide lines. It may be of either cardboard or wood. The angle, or slant, for the templet may be found by stepping off on a vertical line of any length points to divide it into eight equal parts and then stepping off three of these equal divisions on a horizontal line, as shown in Fig. 63. A line drawn through the extremities of the vertical and horizontal lines will give the hypotenuse of a triangle of the correct angle, or slant, and this angle may be laid off on a templet of any size. If desired, the slant of the letters may be made 60°, and the guide lines for this angle may be drawn by use of the triangle as shown in Fig. 64.

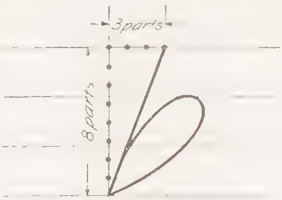


FIG. 63

74. In the drawing work of this Course, the height of the capital letters is to be $\frac{1}{8}$ inch and that of the lower-case letters two-thirds of this, or $\frac{1}{12}$ inch.

The practice in drawing rooms is to letter drawings freehand without the use of guide lines, but until the student becomes proficient in lettering, horizontal guide lines laid off as shown in Fig. 64 may be used for the height of letters. Sheets ruled with these guide lines will be furnished to the student for practice. Proficiency in lettering freehand can be attained only by persistent practice. This may be begun by laying off in pencil slanting guide lines, as shown in Fig. 64, using these until the hand becomes accustomed to the slope and confidence is obtained, after which the practice should be in making the letters without the aid of guide lines.

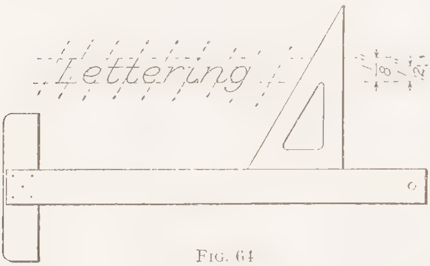


Fig. 64

In practicing the drawing of letters, care should be taken to have the slant and curved lines of all letters extend fully to the guide lines, and the letters should be of proportional width. If these instructions are not carefully followed the letters will present an uneven appearance. The difference in the appearance of a word when the letters are well made and when they are poorly made is shown in Fig. 65. In the first example, the letters are of uniform height and slant and of proportional width, consequently the word presents a good appearance; in the second example, the letters are not uniform in height or slant and are not proportional in width; consequently, the word presents a poor appearance.

Care should be taken to have the ascending stems of letters, as *b*, *d*, *f*, etc., extend fully to the upper guide line; the descending stems of letters, as *f*, *g*, *j*, etc., should extend the same distance below the base guide line that the ascending stems extend above the guide line for the height of the lower-case letters.

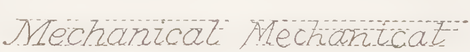


Fig. 65

The rounded letters, as *c*, *e*, and *o*, are usually the most difficult to make, and close attention should be given to their

construction. The loops and curves of letters should be practiced until the hand becomes so accustomed to the movements that they can be made with ease and facility.

75. Another style of slant lettering is shown in Fig. 66. This style differs from the style shown in Fig. 60 only in that

ABCDEFGHIJKLMNOPQRSTUV
WXYZ& 1234567890
abcdefghijklmnopqrstuvwxyz
Cast Iron 1234567890 $2'$-$6\frac{1}{4}''$ dia.

FIG. 66

the letters are made a little rounder and are finished with *spurs*, or *ceriphs*. On account of the ceriphs this style is a little more difficult to make than the style shown in Fig. 60, but with this exception the same instructions apply to both.

76. In lettering drawings, it is common practice to use capital and lower-case letters, in the same manner as in ordinary printed matter. In some drawing rooms, however, capitals and small capitals are used for notes on drawings, in the manner shown in Fig. 67. When so used, the large capitals are made $\frac{1}{8}$ inch high and the small capitals $\frac{1}{12}$ inch.

77. Particular attention should be paid to the formation of numerals, as they are extensively used on drawings, and it is therefore important that they be formed with such exactness, particularly on working drawings, that a mistake in reading them will not be made. The numerals are made $\frac{1}{8}$ inch high, the same as the capital letters. The curve enters into the formation of many of the figures, as will be seen by referring to Fig. 61. The forms of the numerals as there shown should be closely studied and the indicated order and direction of strokes followed. The bottom of the figure *2* and the top of the figure *7* may be either a straight or a curved line.

ALL MATERIAL CAST IRON
UNLESS OTHERWISE ORDERED

FIG. 67

The figures of both the numerator and the denominator of fractions are made the same height as the lower-case letters, as

shown in Fig. 68. By allowing a small space between them for the horizontal dash, the total height of the fraction will be $\frac{7}{32}$ inch. The dividing line of the figures of a fraction should always be a horizontal stroke. A slanting stroke is never used on drawings for this purpose, as it is liable to cause a mistake in reading dimensions.

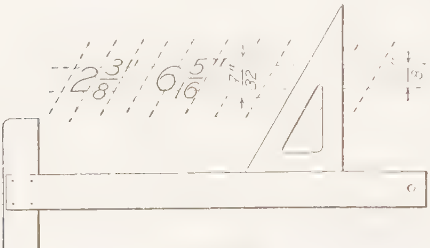


Fig. 68

78. On drawings, the signs for feet and inches are used after numerals. The sign for feet (′) is made with a short, tapering stroke somewhat thicker at the top than at the bottom; the sign for inches (″) is two strokes made in the same way. Care should be exercised to have the strokes begin slightly above the figure and not to make them too long. Careful draftsmen always use a short dash between the figures denoting feet and inches; thus, *10′–5″*. This is done as a precaution against the misreading of dimensions. When only feet are given, this is emphasized by placing after the figures a dash and a cipher followed by the inch sign: thus, *10′–0″*; dimensions less than a foot are indicated thus: *0′–6″*.

SINGLE-STROKE VERTICAL LETTERING

79. A single-stroke vertical letter of the style sometimes used for drawings is shown in Fig. 69. This is a good form of

Fig. 69

letter, but the beginner will find it harder to make the strokes uniform than in the case of slanting letters, which are also more

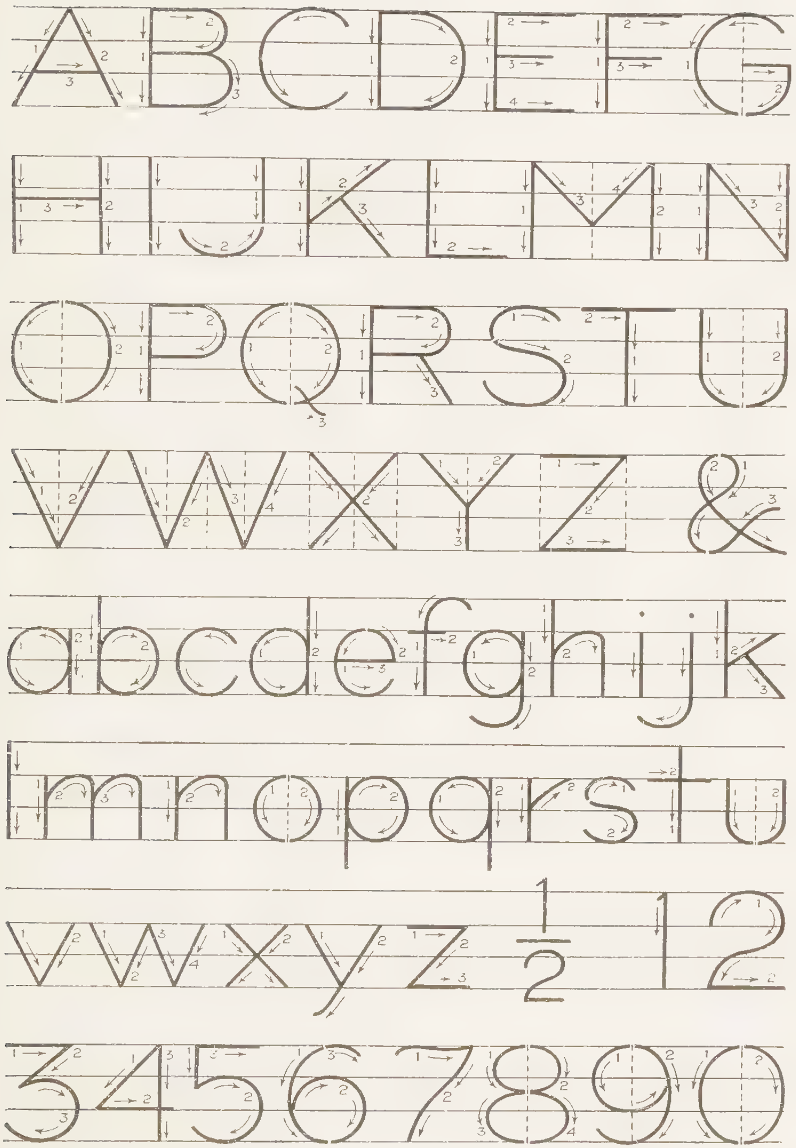


Fig. 70

easily condensed. The formation of the vertical style of letters is shown to an exaggerated scale in Fig. 70, which also shows the order and direction of the strokes. The forms should be carefully studied and the order and direction of strokes followed. The rules given for the spacing of slanting letters will apply to the spacing of the vertical style.

It will be found necessary on some of the drawing plates of this Course, on account of limited space, to draw the letters less than $\frac{1}{8}$ inch high and more condensed. Guide lines similar to those used in forming the slanting style will be found serviceable.

BLOCK LETTERS

80. The form of letter shown in Fig. 71 is called the **block letter,** and is used for the large headings, or titles, of the Plates.

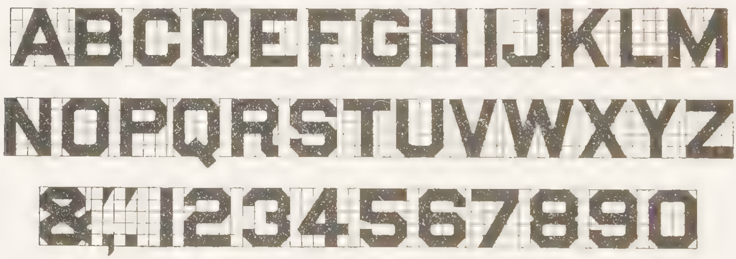


FIG. 71

This alphabet is not to be used on the first five Plates given in the succeeding Section.

The letters and figures are to be made $\frac{5}{16}$ inch high and $\frac{1}{4}$ inch wide, except *A*, *I*, *L*, *M*, and *W*, and the numerals *1* and *4*.

The width of any letter or numeral can be readily determined by referring to the illustration, where each is shown crossed with $\frac{1}{16}$-inch squares.

The width of the spaces between the letters depends on the combination of the letters in words; the best plan to follow in this alphabet is to compare the spacings between the various letters shown in the illustration. Note the space between the

letters *A* and *B* and compare it with that of *B* and *C*, and follow this plan throughout.

To begin to draw the letters, draw in pencil six horizontal lines as guide lines to represent the thickness of the letters at the top, center, and bottom; then by the use of the triangle, the width of the letters, with the proper spaces between them, should be drawn in lead pencil, and the areas of the letters that are to be inked may be penciled over lightly to avoid the possibility of errors in inking. The outlines of the letters should then be inked in with a ruling pen and filled in with a lettering pen. The corners may be drawn with a 45° triangle.

It is well to ink all the vertical lines first, then the horizontal lines, and, finally, the oblique lines.

81. A sloping form of letters somewhat resembling the block letters is shown in Fig. 72. This style of letters will be used for the main titles on subsequent drawing work.

The letters are to be made $\frac{1}{4}$ inch high and $\frac{1}{4}$ inch wide, with the exception of the letters *M*, *W*, and *I*. The width of the

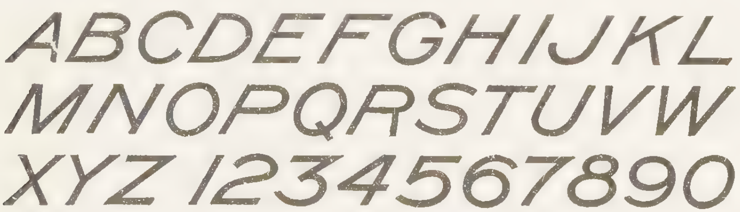


Fig. 72

letter *M* is $\frac{5}{16}$ inch; the letter *W* is $\frac{3}{8}$ inch wide. The letter *I* and the numeral *1* are made with a single stroke, which is $\frac{1}{32}$ of an inch in width.

The slant of the lettering is 60° and is made with a triangle.

To draw these letters, lay off two horizontal guide lines $\frac{1}{4}$ inch apart as shown in Fig. 73.

The rules given for spacing the single-stroke letters apply to this alphabet also.

By using a few simple guide lines, letters may be more easily constructed, as shown in Fig. 73. To draw the letter *A*, use a center line and have the two slanting strokes of the letter

equidistant from it at the base line. The slant sides should not meet in a point at the top, as sufficient allowance must be made for the thickness of the stroke, which is added on the inside when inking.

Similar letters having slanting strokes, as *M*, *V*, and *W*, are drawn in like manner, care being taken that the thickness of the stroke is added on the side where it is required.

The letter *B* is constructed between two slanting guide lines $\frac{1}{4}$ inch apart and the horizontal bar separating the two lobes is drawn slightly above the center. The lobes are connected to the horizontal guide lines at a point determined by a slanting guide line located at a distance of one-third the width of the letter. The upper lobe is also made narrower than the lower one.

The letter *R* is constructed in a similar manner to the letter *B*; the upper part is made the full width and the cross-bar

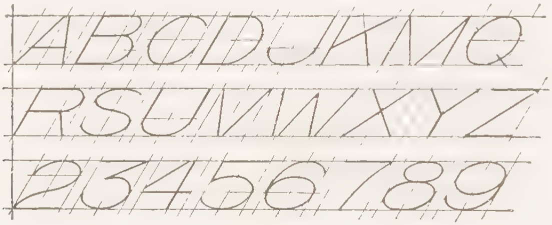


FIG. 73

is midway between the horizontal guide lines. The angle at which the tail is drawn is determined by a guide line located at a distance of one-third the width of the letter from the right-hand edge.

The method of constructing the letters shown in Fig. 73 will be plain from a study of the illustration.

After the letters are penciled they may be inked with a ruling pen; the curves are made freehand with a lettering pen.

The numerals are constructed in like manner to the letters. By taking particular note where the curved parts are tangent to the guide lines, well-formed letters will be produced.

GEOMETRICAL DRAWING

(PART 2)

INTRODUCTION

1. Purpose and Use of Geometrical Drawing Problems.—In this Section are treated the methods of solving certain geometrical problems by the use of drawing instruments.

By the methods here explained it is possible to locate points, lines, angles, etc., without resorting to calculations. The solutions are founded on proved geometrical principles, and the methods given may be used with assurance that correctness in the results depends only on accuracy in drawing. A complete understanding of the methods by which these principles are proved, and upon which the constructions are based, requires a somewhat extended knowledge of geometry, but it is not necessary to understand the proofs in order to make use of the solutions for the purpose for which they are here used and for the every-day work of the draftsman, therefore the proofs are not given.

The problems here treated underlie all work in geometrical drawing, and their application to practical work will be evident as experience is gained. The most important things to be learned in the beginning are (1) to handle the drawing instruments skilfully, (2) to make neat and accurate constructions of the problems, and (3) to print well-proportioned and well-formed title headings and statements of the problems.

When the principles have been mastered, it will not be difficult to do the succeeding plates, which are directly applicable to practical work.

GEOMETRICAL DRAWING PROBLEMS

PRELIMINARY DIRECTIONS

2. The Drawing Plates.—The size of the drawing paper to be used for the drawing work given in this Section is 15 in. ×20 in. Border lines enclosing a rectangle 13 in.×17 in. are to be drawn in pencil and are to be inked in when the drawing is completed, and outside of this border line and $\frac{1}{2}$ inch from it all around another pencil border line is to be drawn. The space on the edges of the sheet outside the pencil lines is to be used for inserting thumbtacks to fasten the sheet on the board and for testing the drawing pen to see whether the ink is flowing well and whether the lines are of the proper thickness. When the drawing is completed the margin of the sheet outside of the pencil lines is to be trimmed off, which will leave the sheet 14 in.×18 in.

3. The drawing work of this Section consists of nine plates, for the making of which full directions are given in the text. The work required on the first five plates consists of solutions of practical geometrical problems that constantly arise in practice, and a knowledge of which is necessary in doing the work on the more advanced plates that follow. A sample copy of the first plate in reduced size will be sent to each student, but no sample copies of the next four plates will be furnished. Sample copies of the sixth and subsequent plates will be furnished in slightly reduced size.

The method of solving each of the problems given for the first five plates should be carefully memorized, so that any one can be instantly applied when the occasion requires without referring to the instructions. Great care should be taken to distribute the different views, parts, etc. on a drawing in such a way that when the drawing is completed one view will not be so near another as to mar the appearance of the work. Until one has gained experience in this, it is advisable to draw

each figure on a separate piece of paper before attempting to locate it on a Plate. This will give familiarity with the construction and also practice in drawing as well as be a help in locating the figure on the Plate. Great care should be taken to lay off dimensions accurately, and the entire drawing should be made in pencil before any part is inked in. In penciling the work, the only distinction that need be made between the construction lines is to make those that are to be inked in a little heavier than those that are not to be. The location of dotted lines may be represented by full pencil lines, which can be made in less time than dotted lines.

The hands should be perfectly clean and should not touch the paper except when absolutely necessary. Construction lines that are to be removed or that are liable to be changed should be drawn lightly, so that the finish of the paper will not be destroyed in erasing them. The methods of removing both pencil and ink lines have been explained in the previous Sections, and those instructions should be carefully followed.

DIRECTIONS FOR SENDING IN WORK

4. The plates are to be sent to the Schools one at a time as they are completed. When you finish Plate I send it to us and then begin work on Plate II. When your first plate is received it will be examined and returned to you promptly with corrections and such suggestions as will aid you in the subsequent work. These corrections and suggestions should receive your careful consideration. In this way you will make better progress than you could otherwise.

It is very important that you comply strictly with the directions. Do not be discouraged if there are a large number of corrections on your early plates; we are merely pointing out ways in which the drawing or lettering can be improved so that your later plates may be as nearly perfect as they can be made. No one can obtain proficiency unless the work is criticized, and we will do our best to help you succeed; we should

not be doing our duty if we did not point out the defects. The *number* of corrections is no indication of our appreciation of the merits of the drawing.

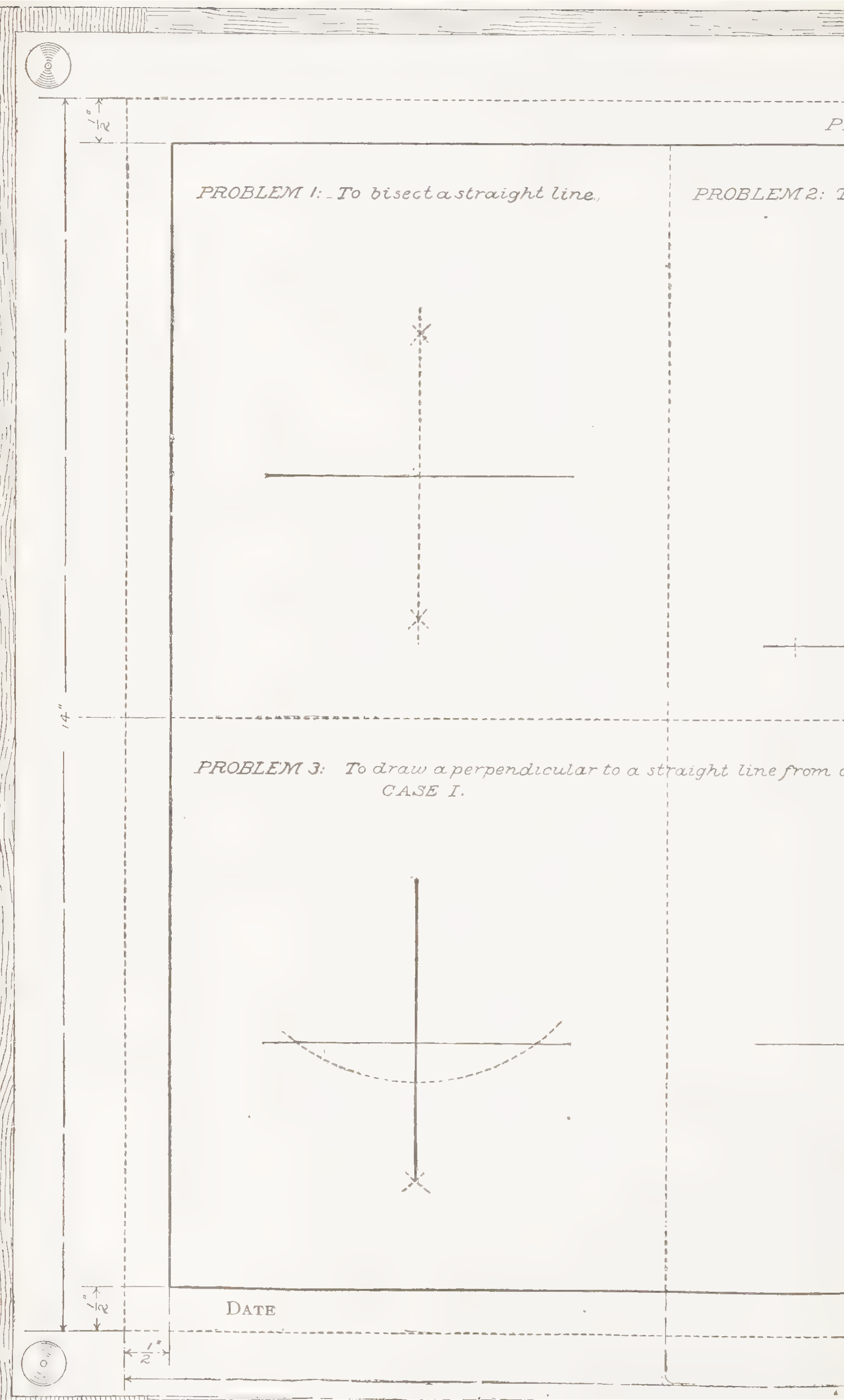
On all plates that you send to us, write your name and address in full in lead pencil on the back of the plates. This should in no case be omitted, as delay in the return of your work will otherwise surely occur.

PLATE I

5. General Directions.—Fasten a sheet of drawing paper to the board as described in the previous Section, then draw the inside border lines to be inked in and outside of these draw the lines to represent the edge of the sheet when it is trimmed, as described in the preliminary directions for this work. The term *drawing* as it will be used hereafter refers to the constructions drawn inside the inked border lines. Before commencing work on Plate I, open the folded sheet inserted at the end of this Section which shows in reduced size Plate I, and spread it before you as a guide. The sample sheet shows the space inside the inked border lines to be divided into six equal rectangular spaces. Now draw midway between the top and the bottom border lines a faint horizontal pencil line on the sheet fastened to the drawing board, thus dividing the space into two equal parts, then divide each of these parts into three equal rectangular spaces by two faint vertical pencil lines. *These division lines are not to be inked in but must be erased when the drawing is completed.*

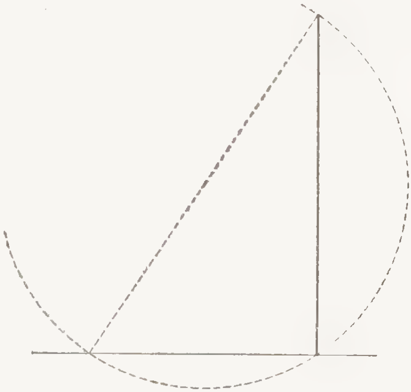
On the first as well as the next four plates, space for the required lettering must be taken into account. The lettering consists of the word "Problem" and its number and a statement of the problem that is to be drawn in each space. This lettering should not be done before the drawing is finished and inked in, and judgment must be used as to the number of lines the lettering will occupy.

The word *Problem*, as indicated in the sample Plate I, is to be in capital letters; and the statement, *To bisect a straight line*, or any similar note, is to begin with a capital letter. The


PROBLEM 1:_To bisect a straight line.
PROBLEM 2:
PROBLEM 3: To draw a perpendicular to a straight line from a
CASE I.
DATE
1/2"
14"
1/2"
1/2"

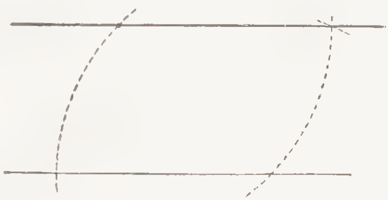
pendicular to a straight line from a given point in that line.

CASE II.



t it.

PROBLEM 4: Through a given point to draw a straight line parallel to a given straight line



NAME, CLASS LETTERS, AND NUMBER

lettering may be of the slanting or vertical single-stroke letters explained in the previous Section. If a student is employed where some other style of lettering is used, no objection will be made to that style being used for this drawing work.

The tops of the capital letters in the first line of the statement are placed $\frac{1}{2}$ inch below the upper border line of the space in which the problem is to be drawn. The space between any two lines of lettering is $\frac{1}{8}$ inch, measured from the base line of the first line of lettering to the tops of the capital letters of the second line.

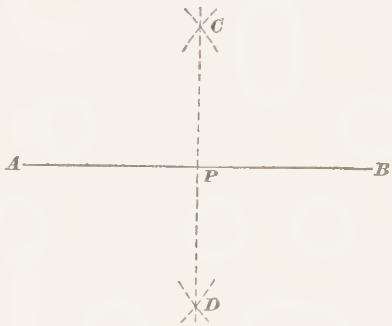


FIG. 1

The height of the capital letters on these plates is to be $\frac{1}{8}$ inch, and that of the small letters is to be two-thirds of this, or $\frac{1}{12}$ inch. To be sure that the heights are uniform, guide lines are drawn in pencil, as indicated in the upper right-hand corner of the sample plate, and the lettering is drawn between them.

The problems are to be centrally located within the six rectangular spaces to insure a neat and well-balanced drawing.

In connection with the descriptions of the plates that follow, the statement of the problem, which is to form the heading, is printed in black-faced type after the problem number.

PROBLEM 1.—**To bisect a straight line.**

See Fig. 1; also Problem 1 of Plate I.

CONSTRUCTION.—With the T square as a guide, draw a horizontal line AB $3\frac{1}{2}$ inches long. With one end, as A, as a center and with the compasses set to a radius greater than one-half of the length of the line AB, describe an arc of a circle on each side of the given line; with the other end B as a center and the same radius, describe arcs intersecting the first two in the points C and D. Join C and D by the dotted line CD, and the point P, where it intersects AB, will be the

required point; then, AP equals PB, and P is the middle point of the line AB. As CD is perpendicular to AB, this construction also gives a *perpendicular to a straight line at its middle point.*

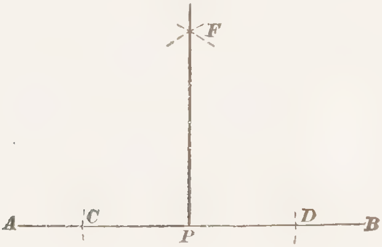


FIG. 2

PROBLEM 2.—**To draw a perpendicular to a straight line from a given point in that line.**

NOTE.—As there are two cases of this problem, requiring two figures on the plate, the line of letters will be run clear across both figures, as shown in sample Plate I.

Case I.—*When the point is at or near the center of the line.* See Fig. 2; also Problem 2, Case I, of Plate I.

CONSTRUCTION.—Draw AB $3\frac{1}{2}$ inches long. Let P be the given point. With P as a center and any radius, as PD, describe two short arcs cutting AB in the points C and D. With C and D as centers and any convenient radius greater than PD, describe two arcs intersecting in E. Draw PE, and it will be perpendicular to AB at the point P.

Case II.—*When the point is near the end of the line.* See Fig. 3; also Problem 2, Case II, of Plate I.

Draw AB $3\frac{1}{2}$ inches long. Take the given point P about $\frac{3}{8}$ inch from the end of the line. With any point O as a center, and a radius OP, describe an arc cutting AB in P and D. Draw DO, and prolong it until it intersects the arc in the point C. A line drawn through C and P will be perpendicular to AB at the point P.

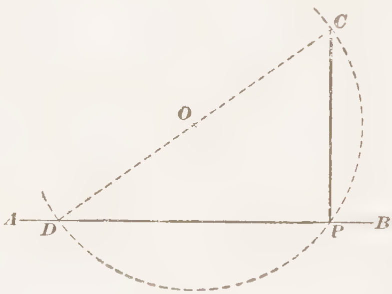


FIG. 3

PROBLEM 3.—**To draw a perpendicular to a straight line from a point without it.**

As in Problem 2, there are two cases.

Case I.—*When the point lies nearly over the center of the line.* See Fig. 4; also Problem 3, Case I, of Plate I.

CONSTRUCTION.—Draw AB $3\frac{1}{2}$ inches long. Let P be the given point. With P as a center and any radius PD greater than the distance from P to AB, describe an arc cutting AB in C and D. With C and D as centers and any convenient radius, describe short arcs intersecting in E. A line drawn through P and E will be perpendicular to AB at F.

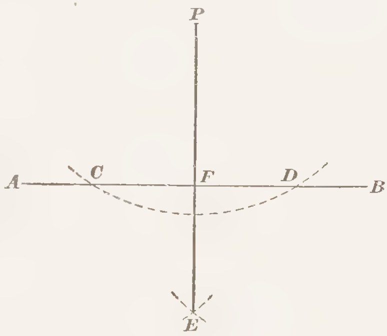


FIG. 4

Case II.—*When the point lies nearly over one end of the line.* See Fig. 5; also Problem 3, Case II, of Plate I.

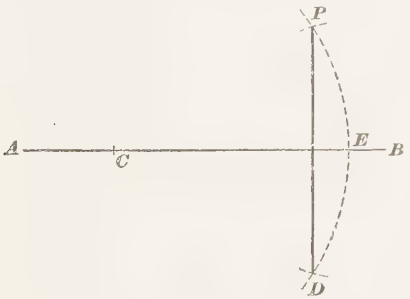


FIG. 5

Draw AB $3\frac{1}{2}$ inches long, and let P be the given point. With any point C on the line AB as a center and with CP as a radius, describe an arc PED cutting AB in E. With E as a center and the distance EP as a radius, describe an arc cutting the arc PED in D. The line joining the points P and D will be perpendicular to AB.

PROBLEM 4.—**Through a given point, to draw a straight line parallel to a given straight line.**

See Fig. 6; also Problem 4 of Plate I.

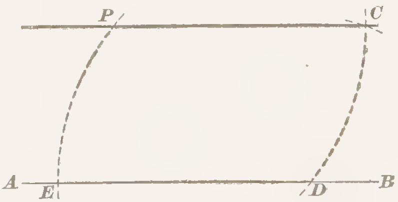


FIG. 6

CONSTRUCTION.—Let P be the given point and AB the given straight line $3\frac{1}{2}$ inches long. With P as a center and any convenient radius, describe

an arc CD intersecting AB in D. With D as a center and the same radius, describe the arc PE. With D as a center and a radius equal to the chord of the arc PE, describe an arc intersecting CD in C. A straight line drawn through P and C will be parallel to AB.

6. These four problems form Plate I. They should be carefully and accurately drawn in with lead-pencil lines and then inked in in the manner described later. It will be noticed that on Plate I, and in Figs. 1 to 6, the given lines are *light*, the required lines *heavy*, and the construction lines, which in a practical working drawing would be left out, are *light dotted*. This system must also be followed in the four plates which are to follow. A single glance enables one to see at once the reason for drawing the figure, and the eye is directed immediately to the required line.

7. In drawing, accuracy and neatness are essential. Be certain that the lines are of *precisely* the length that is specified in the description. When drawing a line through two points, be sure that the line goes through the points; if it does not pass exactly through the points, erase it and draw it over again. If a line is supposed to end at some particular point, make it end there—do not let it extend beyond or fall short. Thus, in Fig. 6, if the line PC does not pass through the points P and C, it is not parallel to AB. By paying careful attention to these points, a great deal of trouble will be avoided.

8. Lines Used on Drawings.—There are five kinds of lines used in drawing, thus:

The light full line.

The dotted line.

The broken-and-dotted line.

The broken line.

The heavy full line.

The **light full line** is used the most; it is used for drawing the outlines of figures and all other parts that can be seen by the eye.

The **dotted line,** consisting of a series of very short dashes, is used in showing the position and shape of that part of the object represented by the drawing which is concealed from the eye in the view shown; for example, a hollow prism closed on all sides. The hollow part cannot be seen; hence its size, shape, and position are represented by dotted lines.

The **broken-and-dotted line,** consisting of a long dash, and with one or two very short dashes repeated regularly, is used to indicate the center lines of the figure or parts of the figure, and also to indicate where a section has been taken when a sectional view is shown. This line is sometimes used for construction lines in geometrical figures.

The **broken line,** consisting of a series of long dashes, is used in putting in the dimensions, and serves to prevent the dimension lines from being mistaken for lines of the drawing.

The **heavy full lines** are made not less than twice as thick as the **light full lines,** and are used for shade lines.

The system according to which shade lines are placed on a drawing will be explained in detail farther on.

9. Inking the Drawing.—To ink the lines of the drawing that has already been made in pencil, first adjust the ruling pen so that the blades practically touch, and put the ink between the blades of the pen with the quill stopper. Then try the pen on the edge of the drawing paper to see whether the blades are set to make a line of the thickness desired and that the ink flows freely. First ink in all the light lines and light dotted lines which have the same thickness; then adjust the pen to the thickness of the heavy lines, test it again, and ink in the lines.

Keep the ruling pen and compass pens clean by wiping the outside and inside of the blades with a damp cloth. India ink dries quickly and soon clogs the blades, so frequent cleaning is necessary to insure an even flow of ink.

10. Lettering and Finishing.—After the drawing has been inked in, it should be lettered. Before attempting this

carefully read the instructions given under the head of Lettering in the previous Section. When the drawing has been finished, the word "Plate" and its number should be lettered at the top of the sheet, outside the border lines, and midway of its length, as shown. The student's name and class letters and number should be lettered in the lower right-hand corner in capital letters. Thus, JOHN SMITH, D Y 618654. The date on which the drawing was completed should be lettered in the lower left-hand corner, also in capital letters. Next erase all pencil lines and clean the drawing by rubbing it very gently with a soft-rubber eraser. Care must be exercised when doing this, or the inked lines will appear of a lighter shade where the eraser has come in contact with them. After the drawing is cleaned, the edges of the sheet should be trimmed off. Finally, write your name and address in full in pencil on the back of the drawing, after which put it in the mailing tube furnished to you and mail it to the Schools according to the directions.

HINTS FOR PLATE 1

11. *Do not forget to make a distinction between the thickness of the given and required lines, nor forget to make the construction lines dotted.*

When drawing dotted lines, take pains to have the dots and spaces uniform in length. Make the dots about $\frac{1}{16}$ inch long and the spaces only about one-third the length of the dots.

Try to get the work accurate. The constructions must be accurate, and all lines or figures should be drawn of the length or size previously stated. To this end, work carefully and keep the pencil leads very sharp, so that the lines will be fine.

The lettering on the first few plates, as well as on the succeeding plates, is fully as important as the drawing, and should be done in the neatest possible manner. Drawings sent in for correction with the lettering omitted will be returned for completion.

The reference letters like A, B, C, etc., as shown in Figs. 1 to 6 of the text, are not to be put on the plates.

Do not neglect to trim the plates to the required size. Do not punch large holes in the paper with the dividers or compasses.

Before mailing your drawing be sure that it is complete in every detail. Do not attempt to hurry this work. Beginners cannot expect to do what experienced draftsmen have taken some time to acquire. What is worth doing is worth doing well.

PLATE II

12. Draw the pencil border lines and the division lines in the same manner as described for Plate I. The following five problems (5 to 9, inclusive) are to be drawn in regular order, as was done in Plate I, with problems from 1 to 4.

PROBLEM 5.—**To bisect a given angle.***

Case I.—*When the sides intersect within the limits of the drawing.* See Fig. 7.

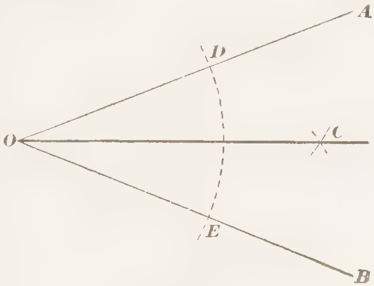


FIG. 7

CONSTRUCTION.—Let AOB be the angle to be bisected. Draw the sides OA and OB $3\frac{1}{2}$ inches long. With the vertex O as a center and any convenient radius, describe an arc DE intersecting OA at D and OB at E. With D and E as centers and a radius greater than half the arc DE, describe two arcs intersecting at C. The line drawn through C and O will bisect the angle; that is, AOC equals COB.

Case II.—*When the sides do not intersect within the limits of the drawing.* See Fig. 8.

CONSTRUCTION.—Draw two lines, AB and CD, each $3\frac{1}{2}$ inches long, and inclined toward each other as shown. With any point E on CD as a center and any convenient radius, describe arc

* Since the statement of this problem is very short, it will be better to place it over each of the two cases separately, instead of running it over the division line, as was done with the long headings of the two cases in Plate I. Put Case I and Case II under the heading, as in the previous plate.

$F\,I\,G\,H$; with G as a center and the same radius, describe arc $H\,L\,E\,F$, intersecting $F\,I\,G\,H$ in H and F. With L as a center and the same radius, describe arc $K\,G\,J$; with I as a center and the same radius, describe arc $J\,E\,K$, intersecting $K\,G\,J$ in K

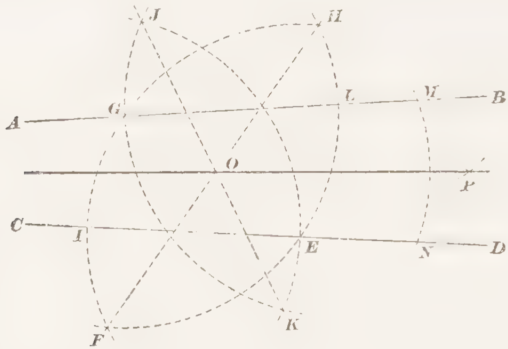


Fig. 8

and J. Draw $H\,F$ and $J\,K$; they intersect at O, a point on the bisecting line. With O as a center and the same or any convenient radius, describe an arc intersecting $A\,B$ and $C\,D$ in M and N. With M and N as centers and any radius greater than one-half $M\,N$, describe arcs intersecting at P. A line drawn through O and P is the required bisecting line.

Problem 6.—**To divide a given straight line into any required number of equal parts.**

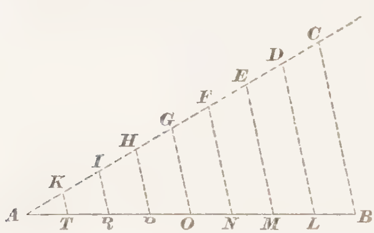


Fig. 9

See Fig. 9.

Construction.—$A\,B$ is the given line $3\frac{7}{16}$ inches long. Suppose that it is required to divide it into eight equal parts. Through one extremity A of the line, draw an indefinite straight line $A\,C$, making any angle with $A\,B$. Set the dividers to any convenient distance, and space off eight equal divisions on $A\,C$, as $A\,K$, $K\,I$, $I\,H$, etc. Join C and B by the line $C\,B$, and through the points D, E, F, G, etc. draw lines $D\,L$, $E\,M$, etc. parallel to $C\,B$, by using the two triangles; these

parallels intersect $A B$ in the points L, M, N, etc., which are equally distant apart. The spaces $L M$, $M N$, $N O$, etc. are each equal to $\frac{1}{8}$ $A B$. By this method, $A B$ can be divided into any number of parts by spacing on $A C$ the number of parts desired and then drawing the parallels, as explained.

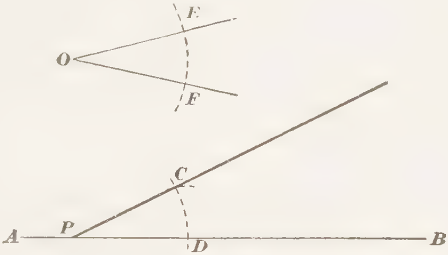


FIG. 10

PROBLEM 7.—**To draw a straight line through any given point on a given straight line to make any required angle with that line.**

CONSTRUCTION.—In Fig. 10, $A B$ is the given line $3\frac{1}{2}$ inches long, P is the given point, and $E O F$ is the given angle. With the vertex O as a center and any convenient radius, describe an arc $E F$ cutting $O E$ and $O F$ in E and F. With P as a center and the same radius, describe an arc $C D$. With D as a center and a radius equal to the chord of the arc $E F$, describe an arc cutting $C D$ in C. A line drawn through the points P and C will make an angle with $A B$ equal to the angle O, or $C P D$ equals $E O F$.

PROBLEM 8.—**To draw an equilateral triangle, one side of which is given.**

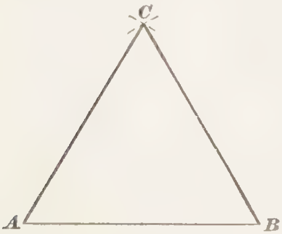


FIG. 11

CONSTRUCTION.—In Fig. 11, $A B$ is the given side $2\frac{1}{2}$ inches long. With $A B$ as a radius and A and B as centers, describe two arcs intersecting in C. Draw $C A$ and $C B$, and $C A B$ is an equilateral triangle.

PROBLEM 9.—**The altitude of an equilateral triangle being given, to draw the triangle.**

CONSTRUCTION.—In Fig. 12, $A B$ is the altitude $2\frac{1}{4}$ inches long. Through the extremities of $A B$ draw parallel lines $C D$

and EF perpendicular to AB. With B as a center and any convenient radius, describe the semicircle $CHKD$ intersecting CD in C and D. With C and D as centers and the same radius, describe arcs cutting the semicircle in H and K. Draw BH and BK, and prolong them to meet EF in E and F. BEF is the required equilateral triangle.

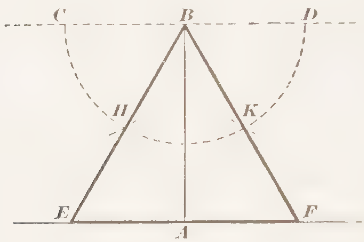


FIG. 12

As each angle of an equilateral triangle is 60°, the same result can be obtained by placing the narrow edge of the 60° triangle along the edge of the **T** square and drawing the line BE to intersect the horizontal lines CD and EF, then reversing the triangle and drawing the line BF to intersect the same horizontal lines.

This problem finishes Plate II. The directions for inking in, lettering, etc. are the same as for Plate I.

PLATE III

13. The border lines for Plate III are to be drawn as explained for the previous plates and the space inside the border lines is to be divided into six spaces in a similar manner.

PROBLEM 10.—**Two sides and the included angle of a triangle being given, to construct the triangle.**

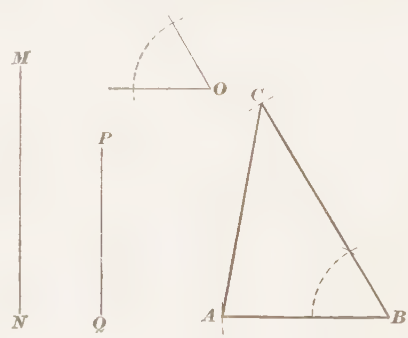


FIG. 13

CONSTRUCTION.—In Fig. 13, make the given sides MN $2\frac{1}{2}$ inches long and PQ $1\frac{7}{8}$ inches long. Let O be the given angle. Draw AB equal in length to PQ. Make the angle CBA equal to the given angle O, and make CB equal in length to the line MN. Draw

CA, and CAB is the required triangle.

PROBLEM 11.—**To draw a parallelogram when the sides and one of the angles are given.**

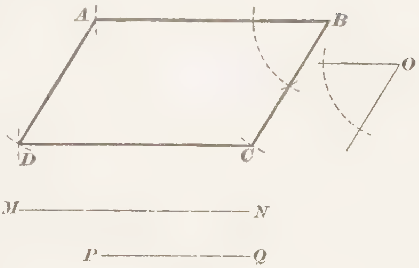


FIG. 14

CONSTRUCTION.—In Fig. 14, make the given sides MN $2\frac{1}{2}$ inches long and PQ $1\frac{7}{8}$ inches long. Let O be the given angle. Draw AB equal to MN, and draw BC, making an angle with AB equal to the given angle O. Make BC equal to PQ. With C as a center and a radius equal to MN, describe an arc at D. With A as a center and a radius equal to PQ, describe an arc intersecting the other arc in D. Draw AD and CD, and $ABCD$ is the required parallelogram.

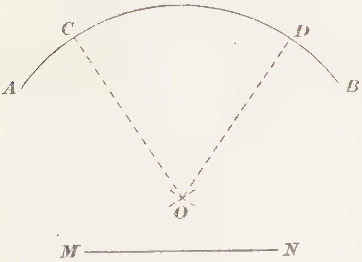


FIG. 15

PROBLEM 12.—**An arc and its radius being given, to find the center.**

CONSTRUCTION.—In Fig. 15, $ACDB$ is the arc, and MN, $1\frac{3}{4}$ inches long, is the radius. With MN as a radius, and any point C in the given arc as a center, describe an arc at O. With any other point D in the given arc as a center and the same radius, describe an arc intersecting the first in O. O is the required center.

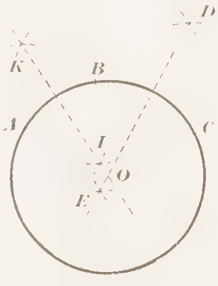


FIG. 16

PROBLEM 13.—**To pass a circumference through any three points not in the same straight line.**

CONSTRUCTION.—In Fig. 16, A, B, and C are the given points. With A and B as centers and any convenient radius, describe

arcs intersecting each other in K and I. With B and C as centers and any convenient radius, describe arcs intersecting each other in D and E. Through I and K and through D and E draw lines intersecting at O. With O as a center and OA as a radius, describe a circle; it will pass through A, B, and C.

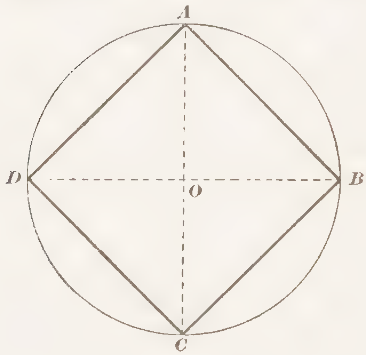


FIG. 17

PROBLEM 14.—**To inscribe a square in a given circle.**

CONSTRUCTION.—In Fig. 17, the circle $ABCD$ is $3\frac{1}{2}$ inches in diameter. Draw two diameters, AC and DB, at right angles to each other. Draw the lines AB, BC, CD, and DA, joining the points of intersection of these diameters with the circumference of the circle, and they will be the sides of the square.

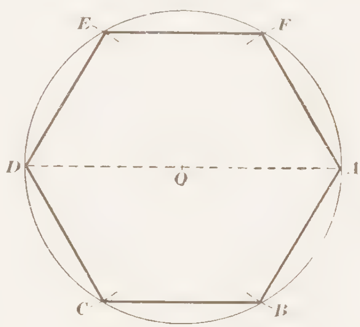


FIG. 18

PROBLEM. 15—**To inscribe a regular hexagon in a given circle.**

CONSTRUCTION.—In Fig. 18, from O as a center, with the compasses set to a radius of $1\frac{3}{4}$ inches, describe the circle $ABCDEF$. Draw the diameter DOA, and from the points D and A, with the compasses set equal to the radius of the circle, describe arcs intersecting the circle at E, C, F, and B. Join these points by straight lines, and they will form the sides of the hexagon. This problem completes Plate III.

PLATE IV

14. The first four problems on this plate are more difficult than any on the preceding plates and will require very careful construction. All the sides of each polygon must be of exactly the same length, so that they will space around evenly with the dividers. The figures should not be inked in until the pencil construction is done accurately. The preliminary directions for this plate are the same as for the preceding ones.

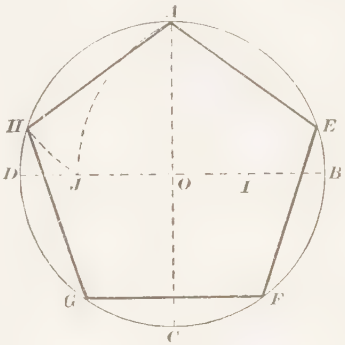


FIG. 19

PROBLEM 16.—**To inscribe a regular pentagon in a given circle.**

CONSTRUCTION.—In Fig. 19, from O as a center, with the compasses set to $1\frac{3}{4}$ inches, describe the circle $A\,B\,C\,D$. Draw the two diameters $A\,C$ and $D\,B$ at right angles to each other. Bisect one of the radii, as $O\,B$, at I. With I as a center and $I\,A$ as a radius, describe the arc $A\,J$ cutting DO at J. With A as a center and $A\,J$ as a radius, describe an arc $J\,H$ cutting the circumference at H. The chord $A\,H$ is one side of the pentagon. With the dividers set to this distance, step off the sides $A\,E$, $E\,F$, etc.

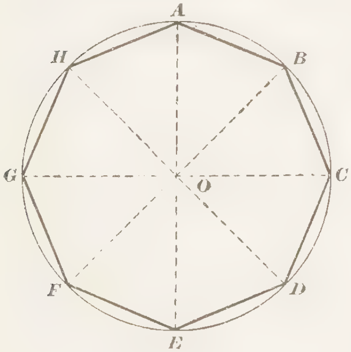


FIG. 20

PROBLEM 17.—**To inscribe a regular octagon in a given circle.**

CONSTRUCTION.—In Fig. 20, from O as a center, with the compasses set to $1\frac{3}{4}$ inches, describe the circle $A\,B\,C\,D\,E\,F\,G\,H$. Draw the two diameters $A\,E$ and $G\,C$ at right angles to each

other. Bisect one of the four equal arcs, as AG, at H, and draw the diameter HOD. Bisect another of the equal arcs, as AC, at B, and draw the diameter BOF. Straight lines drawn from A to B, from B to C, etc. will form the required octagon.

PROBLEM 18.—**To inscribe a regular polygon of any number of sides in a given circle.**

CONSTRUCTION.—With O, Fig. 21, as a center and a radius equal to $1\frac{3}{4}$ inches, describe the circle $A\,7\,B\,C$. Let $A\,7\,B\,C$ be the given circle in which it is required to inscribe a regular polygon of any number of sides. Draw the two diameters $C\,7$ and $A\,B$ perpendicular to each other. Divide the diameter $C\,7$ into as many equal parts as the polygon has sides. We have chosen to inscribe a heptagon, so that the diameter is divided into seven equal parts. Prolong the diameter $A\,B$ and with C or 7 as a center and $C\,7$ as a radius, describe an arc to intersect the vertical center line $A\,B$ at $3'$. Through $3'$ and 2, the second division from C on the diameter $C\,7$, draw the line $3'\,D$ cutting the circumference at D. Draw the chord $C\,D$, and it is one side of the required polygon. With the dividers set equal to $C\,D$, step off the circumference. The end of the seventh division should coincide exactly with the beginning of the first. The length of each side of any regular polygon is always determined by a line drawn from $3'$ through the second horizontal division on $C\,7$ to intersect the circumference, as at D, in Fig. 21.

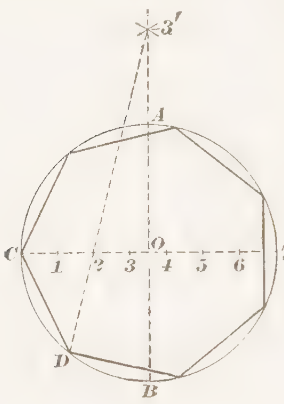


FIG. 21

The draftsman frequently solves this problem by "spacing." This method requires practice, as the spacing may require several adjustments of the dividers, but it should be practiced, as the mechanical draftsman must be expert in the use of drawing instruments.

PROBLEM 19.—**The side of a regular polygon being given, to construct the polygon.**

CONSTRUCTION.—In Fig. 22, let AC be the given side $1\frac{1}{4}$ inches long. The polygon is to have eight sides. Produce AC to B. From C as a center and with a radius equal to CA, describe the semicircle $A\,1\,2\,3\,4\,5\,6\,7\,B$, and divide it into as many equal parts as there are sides in the required polygon (in this case eight). From the point C, and through the second division from B, as *6*, draw the straight line $C6$. Bisect the lines AC and $C6$ by perpendiculars intersecting in O. From O as a center and with OC as a radius, describe the circle $CAHGFED6$. From C, and through the points *1*, *2*, *3*, *4*, *5* in the semicircle, draw lines CH, CG, CF, etc., meeting the circumference. Joining the points *6* and D, D and E, E and F, etc. by straight lines will complete the required polygon.

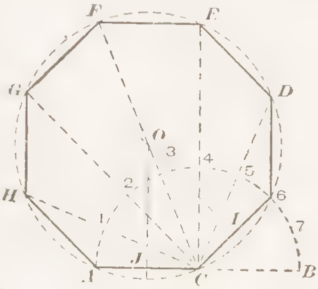


FIG. 22

PROBLEM 20.—**To find an arc of a circle having a known radius, which shall be equal in length to a given straight line.**

NOTE.—There is no exact method, but the following approximate method is close enough for all practical purposes when the required arc does not exceed one-sixth of the circumference.

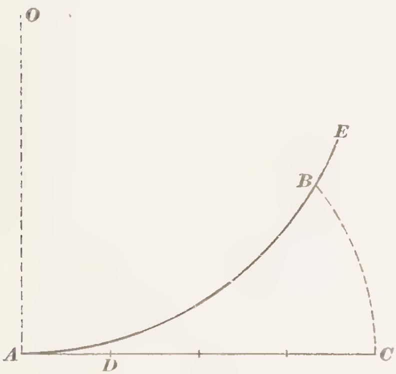


FIG. 23

CONSTRUCTION.—In Fig. 23, let AC be the given line $3\frac{1}{2}$ inches long. At A, erect the perpendicular AO, and make it equal in length to the given radius, say 4 inches long. With OA as a radius and O as a center, describe the arc ABE. Divide AC into four equal parts, AD being the first of these

parts, counting from A. With D as a center and a radius DC, describe the arc CB intersecting ABE in B. The length of the arc AB very nearly equals the length of the straight line AC.

PROBLEM 21.—**An arc of a circle being given, to find a straight line of the same length.**

This is also an approximate method, but close enough for practical purposes, when the arc does not exceed one-sixth of the circumference.

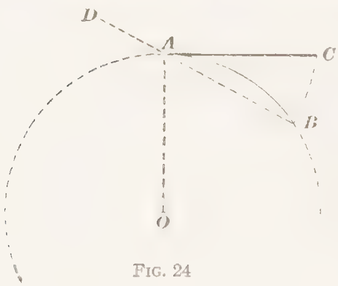


FIG. 24

CONSTRUCTION.—In Fig. 24, let AB be the given arc drawn with the radius OA. For this problem, choose the arc so that the radius will not exceed $1\frac{3}{4}$ inches. At A, draw AC perpendicular to the radius (and, of course, tangent to the arc). Draw the chord AB, and prolong it to D, so that AD equals $\frac{1}{2}$ the chord AB. With D as a center and a radius DB, describe the arc BC cutting AC in C. AC will be very nearly equal to the arc AB.

PLATE V

15. On Plate V there are five problems instead of six, as on the preceding plates. It should be divided into six equal parts, or divisions, as in the previous cases. The two right-hand end divisions are used to draw in the last figure of Plate V, which is too large to put in one division.

PROBLEM 22.—**To draw an egg-shaped oval.**

CONSTRUCTION.—In Fig. 25, on the diameter AB, which is $2\frac{3}{4}$ inches long, describe a circle $ACBG$. Through the center O, draw OC perpendicular to AB, cutting the circumference $ACBG$ in C. Draw the straight lines BCF and ACE. With B and A as centers and the diameter AB as a radius,

describe arcs terminating in D and H, the points of intersection with BF and AE. With C as a center, and CD as a radius, describe the arc DH. The curve $ADHBG$ is the requred oval.

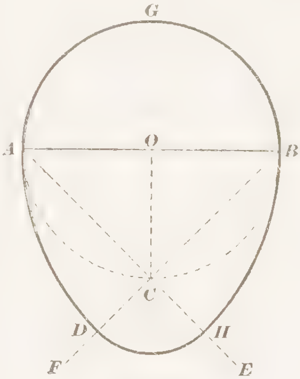


FIG. 25

PROBLEM 23.—**To draw an ellipse, the diameters being given.**

CONSTRUCTION.—The ellipse to be constructed is to have a long diameter, or major axis, of $3\frac{1}{2}$ inches and a small diameter, or minor axis, of $2\frac{1}{4}$ inches. Draw two concentric circles, using radii of lengths equal to one-half those of the given diameters of the ellipse. Then, as in Fig. 26, through the common center O, draw vertical and horizontal center lines, AC being equal to the long diameter and BD equal to the short diameter of the ellipse.

From the center O to the circumference of the large circle, draw any desired number of radial lines, as r, s, t, u, v, which also pass through the circumference of the smaller concentric circle in points r', s', t', u', v'.

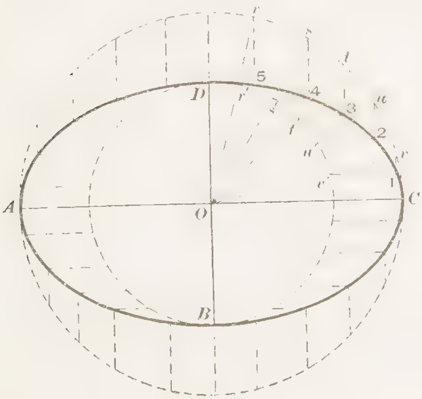


FIG. 26

From the points where the radial lines intersect the circumference of the larger circle, as r, s, t, u, v, draw vertical lines parallel to BD, and from the points where the radial lines intersect the circumference of the smaller circle, as r', s', t', u', v', draw horizontal lines parallel to AC; the points where these lines intersect, as *5, 4, 3, 2, 1*, are points through which the curve of the ellipse is to be drawn.

Trace a curve with the pencil through the points thus found by placing a celluloid irregular curve on the drawing in such a manner that one of its bounding lines will pass through three or more points, judging with the eye whether the curve so traced bulges out too much or is too flat. Then adjust the curve again, so that its bounding line will pass through the next three or more points, and so on, until the curve is completed. Considerable practice is required to be able to draw a good curved line in this manner, and the general appearance of the curve thus drawn depends a great deal on judgment and accuracy.

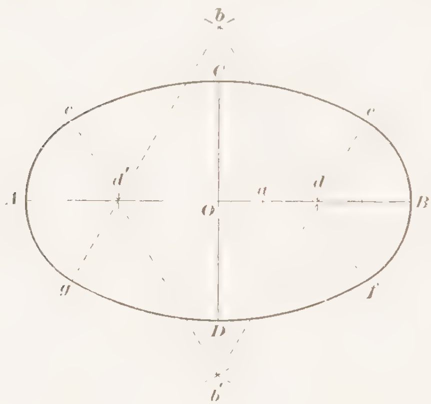


FIG. 27

When inking, do not fail to place a piece of paper folded double the thickness under the irregular curve to raise it slightly from the paper to guard against making blots caused by the ink flowing onto the under side of the curve.

PROBLEM 24.—**To draw an ellipse by circular arcs.**

An ellipse made with circular arcs is not true in form but the method is very convenient for many purposes.

CONSTRUCTION.—See Fig. 27. Use the same dimensions as in Problem 23. On the major axis $A\ B$, set off $A\ a$ equal to $C\ D$, the minor axis, and divide $a\ B$ into three equal parts. With O as a center, and a radius equal to the length of two of these parts, describe arcs cutting $A\ B$ in d and d'. On $d\ d'$ as a side, construct two equilateral triangles $d\ b\ d'$ and $d\ b'\ d'$. With b as a center and a radius equal to $b\ D$, describe the arc $g\ D\ f$ intersecting $b\ d\ f$ and $b\ d'\ g$ in f and g. With the same radius and b' as a center, describe the arc $c\ C\ e$ intersecting $b'\ d'\ c$ and $b'\ d\ e$ in c and e. With A and B as centers and a radius $A\ c$ or $B\ e$, describe arcs cutting $A\ B$ very near to d' and d.

From the points of intersection of these arcs with the line *A B* as centers and the same radius, describe the arcs *c A g* and *e B f*.

PROBLEM 25. **To draw a parabola, the axis and longest double ordinate being given.**

EXPLANATION.—The curve shown in Fig. 28 is a **parabola.** This curve and the ellipse are the bounding lines of certain sections of a cone. The line *O A*, which bisects the area included between the curve and the line *B C*, is called the **axis.** Any line, *B A* or *A C*, drawn perpendicular to *O A*, and whose length is included between *O A* and the curve, is

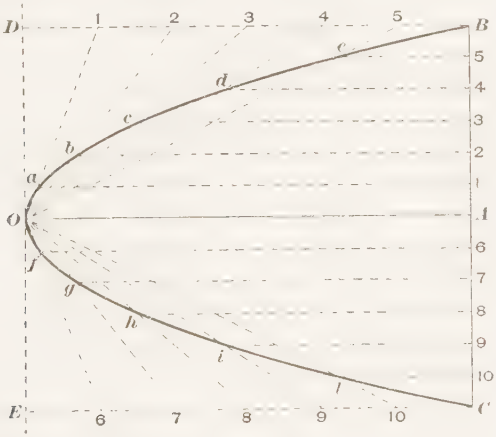


FIG. 28

called an **ordinate.** Any line, as *B C*, drawn from one side of the curve to the other, is called a **double ordinate.** The point *O* is called the **vertex.**

CONSTRUCTION.—Make the axis *O A* equal to $3\frac{1}{2}$ inches, and the longest double ordinate *B C* equal to 3 inches. *B A*, of course, equals *A C*. Draw *D E* through the other extremity of the axis and perpendicular to it; also draw *B D* and *C E* parallel to *O A* and intersecting *D E* in *D* and *E*. Divide *D B* and *A B* into the same number of equal parts, as shown (in this case six); through the vertex *O*, draw *O 1*, *O 2*, etc. to the points of division on *D B*, and through the corresponding

points *1*, *2*, etc., on *A B*, draw lines parallel to the axis. The points of intersection of these lines, *a*, *b*, *c*, etc., are points on the curve, through which it may be traced. In a similar manner, draw the lower half *O f g h i l C* of the curve.

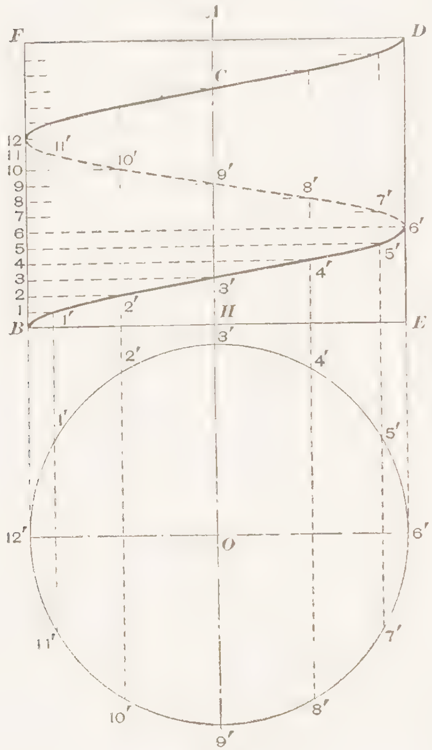


FIG. 29

PROBLEM 26.—To draw a helix, the lead and the diameter being given.

In Fig. 29 is shown a rectangle *F D E B*, which represents a cylinder standing in a vertical position, as indicated by the axis *A O* passing through its center. Below this view of the cylinder is a circle that represents the bottom view. On the cylindrical surface *F D E B* is shown a curved line known as a **helix.** As this helix advances around the cylinder it describes a curved path *B 1′ 2′ 3′*, etc., as shown. The distance that the curved line advances lengthwise of the cylinder during one complete revolution is the **lead.** The term *pitch* is sometimes used instead. The use of the term pitch in this connection is likely to cause confusion, as will be seen from the discussion of screw threads when the subject of *Mechanical Drawing* is reached. The lead of the helical curve is the distance from a point on the curve to a corresponding point on the same curved line measured parallel to the axis of the cylinder when the curve has made one complete revolution on the cylinder.

The helical curve and the lead can be illustrated more clearly by cutting a piece of paper *A* to triangular shape, as shown in Fig. 30. This triangular piece of paper, or pattern, has a right angle at *a*; its length *a b* is equal to one and one-half times the circumference of the cylinder, its side *a c* is equal to the height of the helical curve, and its hypotenuse is equal to one and one-half turns of the curve. If this piece of paper is wound on the cylinder *B*, its horizontal length *g d′* will be found to cover one-half the cylinder; its horizontal length *h e′* will cover the entire surface, its full length will cover the cylinder one and one-half times, and its hypotenuse will produce on the cylinder the helical curve *c′ d e b′*. The distance *c′ e* is the lead.

Construction.—Only Fig. 29 is to be drawn on the plate and, as mentioned before, this figure is to occupy two spaces. The

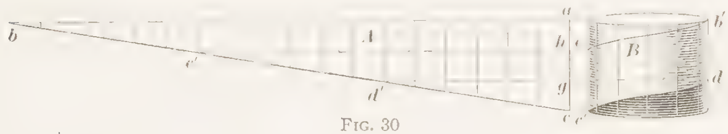


Fig. 30

diameter of the cylinder is $3\frac{1}{2}$ inches, the lead is 2 inches, and a turn and a half of the helix is to be shown. The rectangle *F B E D* is a side view of the cylinder, and the circle *1′ 2′ 3′ 4′*, etc. is a bottom view. It will be noticed that one-half of a turn of the helix is shown dotted; this is because that part of it is on the side of the cylinder that cannot be seen. Lines that are hidden are drawn dotted. Draw the axis *O A* in the center of the space. Draw *F D* $3\frac{1}{2}$ inches long and 4 inches from the top border line; on it construct a rectangle whose height *F B* equals 3 inches. Take the center *O* of the circle $2\frac{3}{4}$ inches below the point *H* on the axis *A O*, and describe a circle having a diameter of $3\frac{1}{2}$ inches, equal to the diameter of the cylinder. Lay off the lead from *B* to *12* equal to 2 inches, and divide it into a convenient number of equal parts (in this case 12), and divide the circle into the same number of equal parts, beginning at one extremity of the diameter *12′–O–6′*, drawn parallel to *B E*. At the point *1′* on the circle divisions,

erect $1'–1'$ perpendicular to $B\,E$; through the point 1 of the lead divisions, draw $1–1'$ parallel to $B\,E$ to intersect the perpendicular in $1'$, which is a point on the helix. Through the point $2'$, erect a perpendicular $2'–2'$, intersecting $2–2'$ in $2'$, which is another point on the helix. So proceed until the point $6'$ is reached; from this point to the point 12, the curve will be dotted. It will be noticed that the points of division $7'$ $8'$, $9'$, $10'$, and $11'$ on the circle are directly opposite the points $5'$, $4'$, $3'$, $2'$, and $1'$; hence, it was not necessary to draw the lower half of the circle, since the point $5'$ could have been the starting point, and the operation could have been conducted backwards to find the points on the dotted upper half of the helix. The other curved full line of the helix can be drawn in exactly the same manner as the first half.

REPRESENTATION OF OBJECTS

16. An object as it appears to the eye may be represented in a drawing by an outline such as would be derived by tracing the form of the object from a photograph, and such an outline would be a good example of a perspective drawing. The perspective drawing shown in Fig. 31 gives as clear an idea of an object as a view of the object itself would give. If, however, the edges $a\,b$ and $c\,d$ are measured on the drawing they will not be found to be the same, as they would be if measured on the object itself. Similarly, the edges $e\,f$, $e\,b$, and $b\,c$, which are equal on the object itself, will not be found to be the same when measured on the drawing.

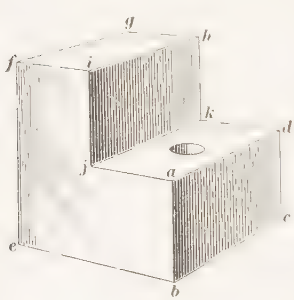


Fig. 31

A perspective drawing, therefore, is unsuitable for obtaining measurements of different parts of an object. The true lengths of lines in perspective can be found only with great difficulty even by persons who are perfectly familiar with the method. What is known as a **projection drawing** is the kind of drawing

universally made when an object is to be represented in its true dimensions, and this kind of a drawing can be made more easily than a perspective drawing.

In general, the size and shape of an object may be shown in three views, namely, a *plan view*, a *front elevation*, and a *side elevation*, as shown in Fig. 32. These views would be meaningless if one did not understand what the lines meant, and to understand what they mean it is necessary to understand how they are obtained.

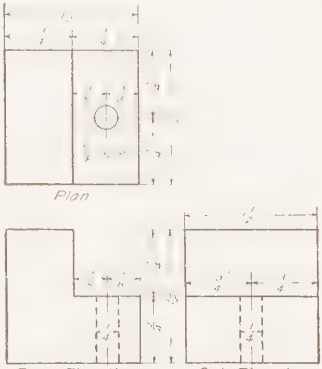


Fig. 32

In Fig. 33, the object shown in Fig. 31 is assumed to be placed within a glass case, and the various views take their names from the different positions of the observer in his view of the object through the transparent sides, or planes. The top plane *1–2–6–7*

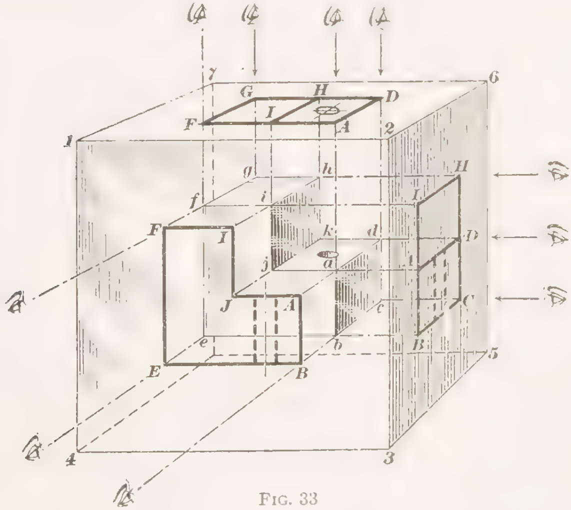


Fig. 33

is parallel to the top surfaces *a d k j* and *f g h i* of the object; the front plane *1–2–3–4* is perpendicular to the top plane and

parallel to the surface *a b c f i j* of the object. The side plane *2-3-5-6* is at right angles to the top plane *1-2-6-7* and also to the front plane *1-2-3-4*; and the planes *2-3-5-6* and *1-2-3-4* are parallel, respectively, to the side and the front surfaces of the object.

17. To understand how views are obtained on any of these planes, assume that we are to obtain first the top view, or plan.

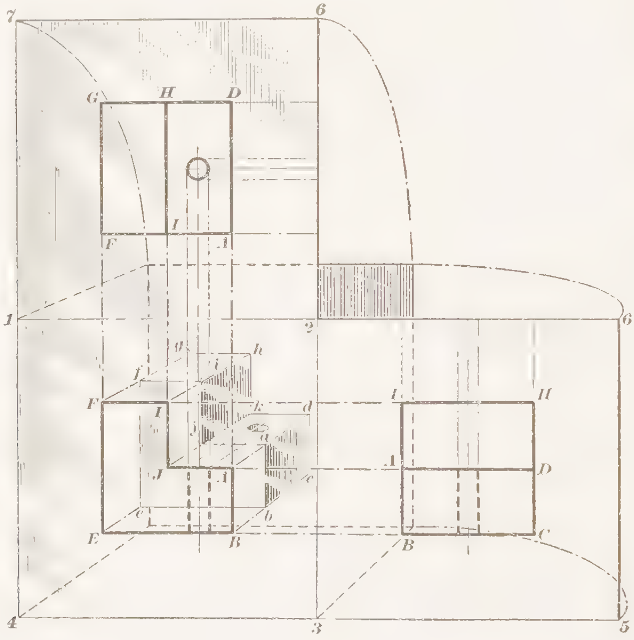


Fig. 34

Imagine that the eye in Fig. 33 is brought successively vertically over the points *a*, *d*, *h*, *g*, *f*, and *i* on the object in the imaginary glass case and that straight lines pass from these points through the transparent horizontal plane to the eye. These lines are sometimes referred to as *lines of sight* but more commonly as *projection lines*, which are always at right angles to the plane. If, now, the top plane is regarded as a sheet of paper and the points where the assumed projection lines intersect

this plane, as A, D, H, G, F, I, are indicated on the paper and the points are connected by straight lines, we will have the rectangle shown in the top view, or plan, of Fig. 32. The round hole in the surface $a\ d\ j\ k$ is represented on the plan by a circle. Before the circle is described its center is located by the intersection of two lines drawn at right angles.

The front elevation $F\ I\ J\ A\ B\ E$, Fig. 33, in the front plane *1–2–3–4* and the side elevation $H\ D\ C\ B\ A\ I$ in the side plane *2–3–5–6* are obtained in a similar manner to the top plane by assuming the line of sight to be in a horizontal direction. In the front and side views, the round hole, instead of being represented by a circle as in the top view, is represented by two dotted lines with a center line between them.

In practice, the three views of an object, instead of being shown on three different planes, are represented on one plane as on a sheet of paper. The relation of the views on a single plane will be better understood by assuming that the top plane of Fig. 33 is hinged along the edge *1–2* and that the side plane is hinged along the edge *2–3*, so that these planes can be swung into the plane of the front view, as shown in Fig. 34. The illustration then represents exactly what is shown in Fig. 32.

18. The lines on which the planes are hinged represent the axis between the views, and they intersect in a center from which arcs may be described to transfer points from one view to another, as shown in Fig. 35. The dimensions may, however, be transferred by the use of dividers, and as this is the customary practice, the lines of the planes and of the axis of revolution are omitted from the drawing. In many cases it is immaterial which view of a drawing is made first; in some cases it is the most convenient to draw the plan first and in other cases to draw the elevation first.

In the preceding discussion, only three views have been considered. The relative location of these views, however, must be fixed firmly in mind in order to read a mechanical drawing easily and to obtain a correct idea of the form of the objects drawn. In all drawings made by this method, the *plan* is always shown at the top, the *front elevation* below it,

and the *right side elevation* at the right of the front elevation, or plan. The views on the three other planes may be obtained in a similar manner by projecting points from the object. The *bottom plan* would be projected on the plane below the front elevation; the *left side view* would be projected to the left of

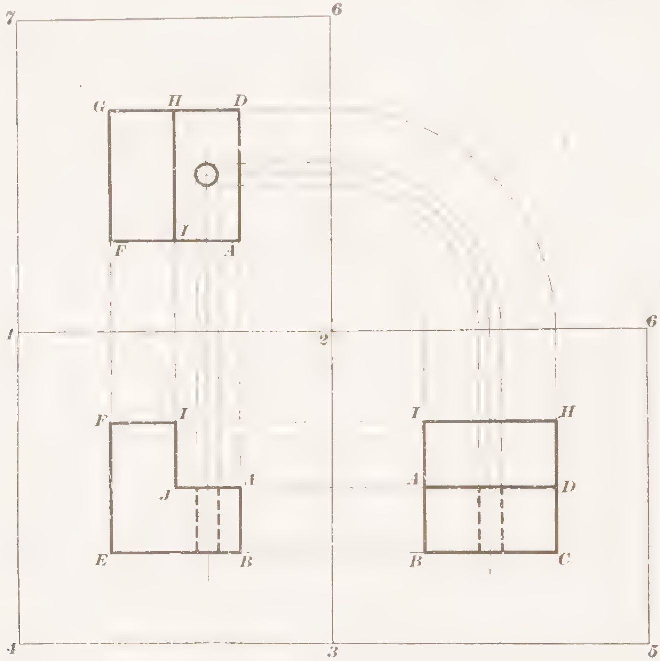


FIG. 35

the front elevation; and the *rear view* would be projected either to the right or the left of the side elevations.

19. The foregoing explanation of the manner in which the different views of an object are obtained on a single plane should have prepared the student for the work on the drawing plates that are to follow, and the work on these plates may now be commenced. In order to distinguish clearly the figure numbers on the plates from those of the figures given in the text, the figure numbers referring to the plates are printed in heavy-faced type.

PROJE

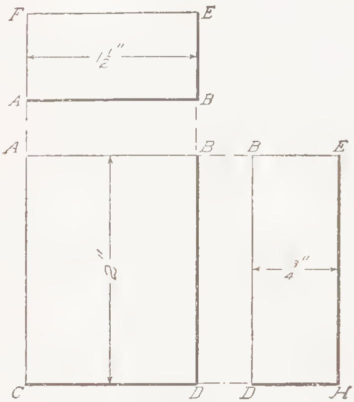


Fig. 1.

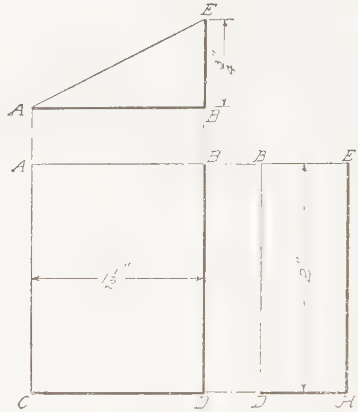


Fig. 2.

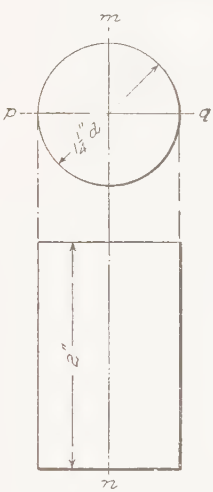


Fig. 5

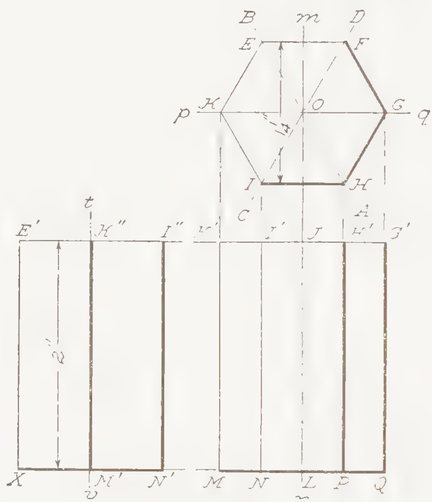


Fig. 6

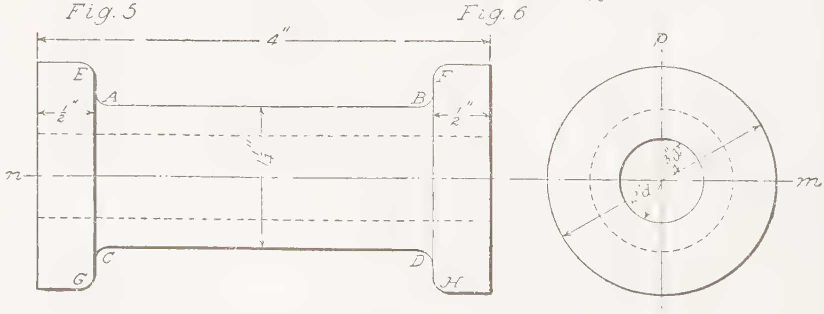


Fig. 10.

NS-I.

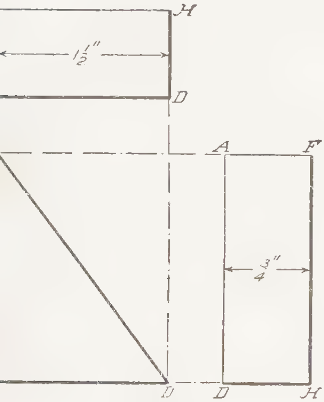


Fig.3.

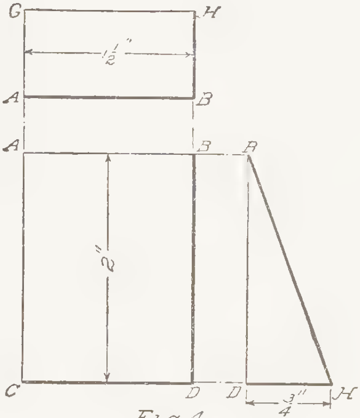
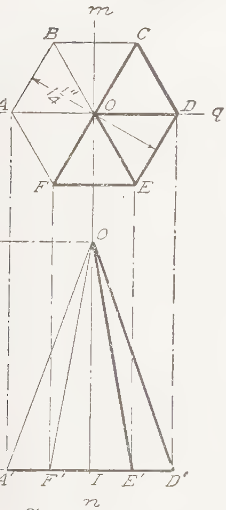


Fig.4.



g.7.

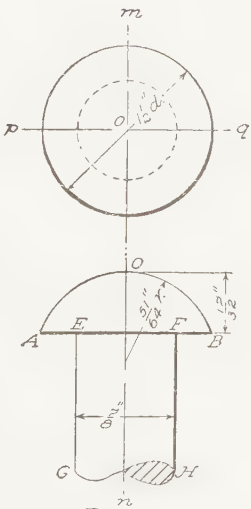


Fig.8.

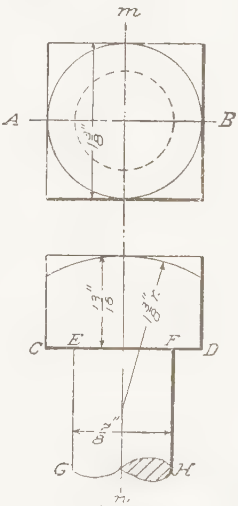


Fig.9.

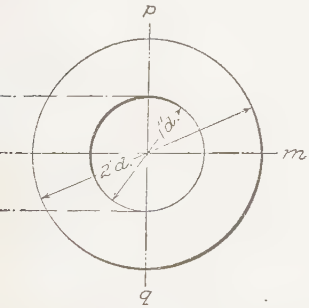


Fig.11.

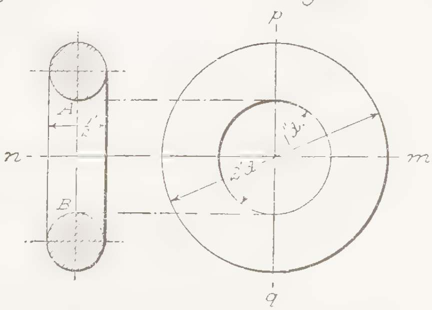


Fig.12.

LLIERY ENGINEER COMPANY
CBOOK COMPANY

NAME, CLASS LETTERS, AND NUMBER

DRAWING PLATE, TITLE: PROJECTIONS—I

20. Arrangement of Figures.—On the preceding plates, the space was divided into a number of equal parts so that the figures of the different problems could be centrally located. The sizes and shapes of the figures for the plates that are to follow differ so widely that it is not advisable to attempt to divide the space into equal parts. Instead, the location of each figure will be given, so that the drawing will have a neat appearance. In no case should a figure come nearer than $\frac{3}{4}$ of an inch to the border line. For this, as well as succeeding plates, border lines are first to be drawn as explained for Plate I.

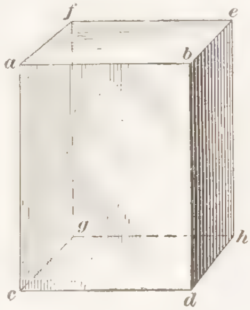


FIG. 36

21. Views of a Rectangular Prism.—In Fig. 36 is shown a rectangular prism standing on one of its ends and of which three views are to be drawn, as shown in Fig. 1 of the drawing plate. The reason why the three views occupy the relative positions shown will be clear from Fig. 37, which shows the prism *X* standing in a glass case and the different views projected on the planes. The front elevation *A B D C* on the plane *1–2–3–4* is a projection of the face *a b d c* of the prism, the side elevation *B E H D* on the plane *2–6–5–3* is a projection of the face *b e h d*, and the top view *A B E F* on the plane *1–2–6–7* is a projection of the face *a b e f*. The views of Fig. 37 are lettered to correspond with

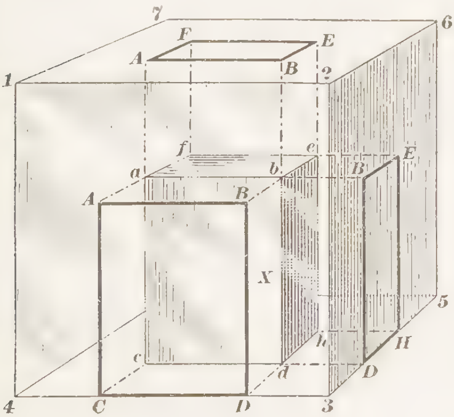


FIG. 37

those on the drawing plate, and if the planes are revolved in the manner previously explained the views will occupy the position shown on the plate.

The prism is 2 inches long, $1\frac{1}{2}$ inches wide, and $\frac{3}{4}$ inch thick. To construct the figure, draw a pencil line across the entire sheet $4\frac{3}{4}$ inches from the upper border line as a base line for the first four figures, and on this base line, $\frac{3}{4}$ inch from the left-hand border line, locate the point C of the front elevation. From the point C lay off $C D$ on the base line the width of the prism, $1\frac{1}{2}$ inches. From these points draw two vertical lines of indefinite length and on these lines lay off the distance $C A$ and $D B$ equal to the height of the prism, 2 inches. The front elevation is completed by drawing the horizontal line $A B$.

To construct the plan, draw horizontal lines $A B$ and $F E$ $\frac{3}{4}$ inch apart to connect the extended vertical lines of the front elevation. To construct the side elevation, extend the line $A B$ and from the points D and H on the base line draw two vertical lines $\frac{3}{4}$ inch apart to intersect the extended horizontal line in the points B and E. This completes the side elevation.

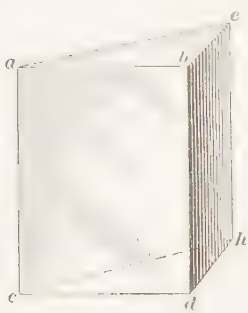


FIG. 38

22. Views of Wedge, Triangular in Plan.—In Fig. 38 is shown a perspective view of a triangular prism, or wedge, of which a drawing is to be made. This triangular prism may be considered as one-half of the prism shown in Fig. 36, since, if the prism were cut vertically along a line from a to e, two triangular prisms like that shown in Fig. 38 would be produced.

To make the drawing, construct the front elevation first, locating point C 5 inches from the left-hand border line, then the side elevation, and the plan last. The front and side elevations are constructed in exactly the same way as for Fig. **1**. The plan, however, is triangular in shape, and a line from A to E completes this view.

23. Views of Wedge, Triangular in Front View. If the rectangular prism of Fig. 36 were cut through from front

to back along a diagonal line drawn from *a* to *d*, a wedge like that shown in Fig. 39 would be produced. The front elevation of this wedge will be a triangle. To obtain the front elevation shown in Fig. **3**, first locate point *C* $7\frac{5}{8}$ inches from the right border line and erect two vertical lines from *C* and *D* at a distance of $1\frac{1}{2}$ inches from each other. Make *A C* 2 inches in height, and from the point *A* in the elevation draw a line to *D*. Then *A C D* is the desired elevation. It will be observed that the triangle *A D C* is just half of the rectangle *a b d c* forming the front face of the rectangular prism of Fig. **1**. The plan and side elevation of the wedge in Fig. **3** are like those of the rectangular prism and are drawn in the same way.

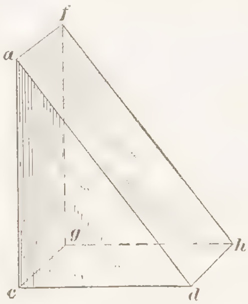


Fig. 39

24. Views of Wedge, Triangular in Side View.—In Fig. 40 is shown a perspective view of a form of wedge obtained by cutting the rectangular prism shown in Fig. 36 along a diagonal line from *b* to *h*. The plan and front elevation in Fig. **4** correspond with those of the prism and are drawn in the same manner. The side elevation, however, is triangular in form and may be drawn by extending the lines *A B* and *C D* horizontally; between the lines thus prolonged draw a vertical line *B D*. From *D* set off horizontally a distance of $\frac{3}{4}$ inch, locating *H*, and draw *B H*. The side elevation *B D H* is thus a triangle, and is one-half of the rectangle *D B H E* forming the side elevation of the rectangular prism shown in Fig. **1**.

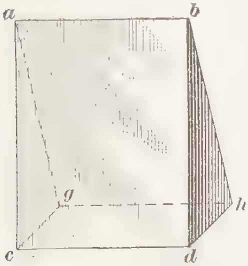


Fig. 40

25. Necessity for Three Views of Some Objects.—A comparison of Figs. **2**, **3**, and **4** with Fig. **1** will serve to show why three views of some objects are necessary in order to fully define their shapes. In Figs. **1** and **2**, the side elevations and front elevations are alike and if no other views were given

it would be impossible to determine whether the objects represented by the two drawings were the same or not. However, as soon as the plan of each is added, it is seen immediately that one is a rectangular prism and the other a triangular prism. In Figs. **1** and **3**, the plans and side elevations are of the same size and shape, but the front elevations differ, thereby showing the difference between the two objects illustrated in the drawings. Again, the front elevations and plans of Figs. **1** and **4** are alike and no difference in the objects represented could be determined by these views alone. By adding the side elevation of each, the difference is at once clearly shown.

26. Views of a Cylinder.—In Fig. **5** is shown a plan and an elevation of a cylinder, 2 inches long and $1\frac{1}{4}$ inches in diameter. The plan, or top view, of this object is a circle, and the front elevation is a rectangle. No side elevation is given, for the reason that it is not needed, as it is the same as the front elevation.

Draw the plan view of Fig. **5** first. Begin by drawing the center line $p\,q$ $6\frac{1}{4}$ inches below the upper border line, and this line may be extended to serve as a guide line for the plan views of Figs. **6** and **7**. Erect the vertical center line $m\,n$ $1\frac{3}{8}$ inches from the left-hand border line, and with the point of intersection of this line with the line $p\,q$ as a center, describe a circle with a radius of $\frac{5}{8}$ inch, thus completing the plan. To construct the elevation, draw a horizontal base line $3\frac{1}{8}$ inches below $p\,q$, and extend this line across the plate to serve as a base line for Figs. **6** and **7**. Project two vertical lines from the horizontal diameter of the circle to intersect the horizontal base line in the elevation. On the center line $m\,n$ locate a point **2** inches above the base line and through this point draw a horizontal line extending to the projected sides, thus completing the elevation.

27. Views of a Hexagonal Prism.—In Fig. 41 is shown a perspective view of a regular hexagonal prism, three views of which are to be drawn as shown in Fig. **6**. The prism is 2 inches long and $1\frac{1}{4}$ inches thick, measured between any two parallel sides.

The plan, which is a regular hexagon, is drawn first, with two of the parallel sides horizontal. To begin, draw a center line $m\,n$ $5\frac{3}{4}$ inches from the left-hand border line and at right angles to it draw the center line $p\,q$. From the point of intersection O as a center and a radius equal to one-half of the distance between two parallel sides ($\frac{1}{2}\times 1\frac{1}{4}''=\frac{5}{8}''$), describe a circle. Now, use the **T** square to draw two horizontal lines of indefinite length through the points of intersection of this circle with the center line $m\,n$. By means of the **T** square and 60° triangle, draw $A\,B$ and $C\,D$ through O, which makes the angles $A\,O\,q$ and $C\,O\,p$ each equal 60°. This is done by keeping the longer of the two short sides of the triangle vertical, and passing the pencil along the hypotenuse.

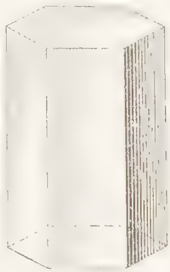


FIG. 11

From the points of intersection of $A\,B$ and $C\,D$ with the two horizontal lines, draw $E\,K$ and $H\,G$ parallel to $C\,D$. From F and I, the points of intersection of $C\,D$ with the same two horizontal lines, draw $F\,G$ and $K\,I$ parallel to $A\,B$. This completes the hexagon, or plan, of the prism.

To draw the front elevation of the prism, measure off from the point L on the center line $m\,n$ a distance of 2 inches, locating the point J, and through this point draw a horizontal line for the top edge of the prism. Project the points K, I, H, and G of the plan to $K'\,G'$, as shown by the projection lines; and through the points of intersection of these projection lines with $K'\,G'$ draw the vertical lines $K'\,M$, $I'\,N$, $H'\,P$, and $G'\,Q$, thus completing the front elevation.

For convenience in this case, the side elevation of the prism is drawn at the left of the front elevation. It could just as well have been drawn at the right, as in previous cases. To draw the side elevation, extend the line $K'\,G'$ to the left and draw the center line $t\,v$. Lay off on each side of the center line a distance equal to one-half the distance between the parallel sides, or $\frac{5}{8}$ inch, and draw vertical lines $E'\,X$, $I''\,N'$. Draw the vertical line $M'\,K''$, which will coincide with the axis, and the side elevation is complete. The sides of the hexagon in the plan should be accurately drawn before projecting them.

28. Views of a Hexagonal Pyramid.—In Fig. **42** is shown a perspective view of a hexagonal pyramid for which views are to be drawn as shown in Fig. **7**. The base is a regular hexagon of the same size as the base of the prism in Fig. **6**. The plan, therefore, is constructed in the same way as for the prism. This gives A, B, C, D, E, F, Fig. **7**. From O, which is located $6\frac{13}{16}$ inches from the right-hand border line and at the intersection of the two center lines, draw lines $O\,A$, $O\,B$, $O\,C$, $O\,D$, $O\,E$, and $O\,F$, which are the horizontal projections of the slanting edges of the pyramid. Then, to draw the front elevation, lay off $O\,I$ on the center line $m\,n$ equal to the altitude, and through I draw the line $A'\,D'$. Project the points D, E, etc. of the plan on $A'\,D'$, as shown by the projection lines, and join them with the point O by the lines $A'\,O$, $F'\,O$, $E'\,O$, and $D'\,O$; these lines are the vertical projections of the edges of the pyramid. The side elevation can be easily drawn, and does not require a special description. The length of the base $B\,F$ is equal to the distance between the parallel sides, or $1\frac{1}{4}$ inches.

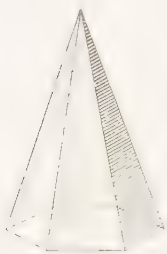


Fig. 42

29. Views of a Rivet.—In Fig. **8** is shown a plan and an elevation of a rivet $\frac{7}{8}$ inch in diameter and having a button head $1\frac{1}{2}$ inches in diameter. A side elevation is not necessary, as it is exactly the same as the front elevation. Draw the plan view first, locating the center line $p\,q$ at a distance of $6\frac{9}{16}$ inches from the lower border line. At the distance of $4\frac{1}{8}$ inches from the right-hand border line draw the vertical center line $m\,n$. With the bow-pencil set to a radius of $\frac{3}{4}$ inch, describe a circle from the point O for the plan view and also a dotted circle from the same center with the bow-pencil set to a radius of $\frac{7}{16}$ inch, or one-half the diameter of the rivet. Now draw a horizontal line of indefinite length at a distance of $1\frac{3}{4}$ inches below $p\,q$ for the base line $A\,B$ of the head of the rivet. Project lines from the points on the circumference of the large circle where it intersects the center line $p\,q$ to intersect the line locating the base line $A\,B$ of the head. On the center line $m\,n$ lay off

the point O $\frac{17}{32}$ inch above the base line $A B$ for the height of the head, and from a center located on the line $m n$ describe with the compasses an arc passing through the points A, O, and B. Now, to complete the figure, project the diameter of the rivet from the dotted circle in the plan and draw the lines $E G$ and $F H$. The irregular line $G H$ indicates that only a part of the rivet is shown. This is done so that too much space will not be taken up on the drawing. This part is shown sectioned to represent wrought iron.

30. Views of a Square-Headed Bolt.—In Fig. 43 is shown a perspective view of an ordinary square-headed bolt of which a plan and elevation is to be drawn as shown in Fig. **9.** The bolt is $\frac{7}{8}$ inch in diameter, has a head $1\frac{3}{8}$ inches square, and is $\frac{13}{16}$ inch thick. To construct the figure, draw a vertical center line $m n$ at a distance of $1\frac{7}{16}$ inches from the right-hand border line and another center line $A B$ at a distance of $6\frac{5}{8}$ inches from the lower border line. Construct the plan view of the head by making a square $1\frac{3}{8}'' \times 1\frac{3}{8}''$. A quick method of constructing the square is to describe a circle with a radius of $\frac{11}{16}$ inch, or one-half the dimensions of the square, and draw vertical and horizontal lines tangent at the points where the center lines $A B$ and $m n$ cut the circle. At a distance of 2 inches below the center line $A B$ draw a horizontal line of indefinite length to locate the line $C D$ representing the lower edge of the head in the elevation. Project the vertical side lines of the plan to the elevation, thus defining the width of the head in the points $C D$. Measure off from the line $C D$ vertically a distance of $\frac{13}{16}$ inch, for the height of the bolt head. The head is to be chamfered at the corners, and this is defined by an arc drawn tangent to the top edge of the bolt head and with a radius of $1\frac{3}{8}$ inches from a point on the vertical center line $m n$. A dotted circle is now drawn in the plan view with a radius of $\frac{7}{16}$ inch, or one-half of the diameter of the bolt. From the plan view the diameter of the bolt is projected to

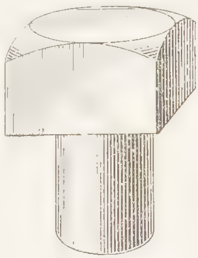


FIG. 43

the elevation and lines $E G$ and $F H$ are drawn. The circle in the plan view is shown dotted to indicate that the bolt cannot be seen in that view.

31. Views of a Distance Piece.—Fig. **10** shows a distance piece used to separate two machine parts a certain distance, and for which a drawing is required. To construct the figure, draw a horizontal center line $n m$ $1\frac{3}{4}$ inches from the lower border line, extend it across the entire sheet to serve for Figs. **11** and **12**, and through this line at a distance of $6\frac{1}{4}$ inches from the left border line draw a center line $p q$ at right angles to it. Draw the side elevation first by describing a circle with a 1-inch radius for the two end flanges. Then describe a dotted circle with the bow-pencil set to a radius of $\frac{5}{8}$ inch to represent the outside diameter of the cylinder and inside it a circle to represent a $\frac{3}{4}$-inch hole through it. Now, draw two vertical lines 4 inches apart to define the total length of the distance piece, and next draw parallel lines $\frac{1}{2}$ inch from each end, to indicate the thickness of the flanges. Project from the side elevation to the front elevation horizontal lines to define the diameter of the flanges and the cylinder between the flanges, and also dotted lines to define the hole through the piece. Use a radius of $\frac{1}{8}$ inch for the fillets at A, B, C, and D and round the corners at E, F, G, and H with the same radius.

32. Views of a Circular Cast-Iron Washer.—In Fig. **11** is shown a circular cast-iron washer square in cross-section. In this case, instead of making an elevation and plan, only an elevation is drawn and a sectional view is taken through this elevation along the line $p q$; that is, the washer is imagined to be cut along the line $p q$, with the part to the left removed, which gives a sectional view as shown.

Begin by drawing a vertical center line $p q$ at a distance of $6\frac{1}{4}$ inches from the right-hand border line and, with the compasses set to a radius of 1 inch, describe a circle representing the outside diameter of the ring, and from the same center, and with a radius of $\frac{1}{2}$ inch, describe another circle representing the inside diameter. Now, to the left of this view, lay off two vertical lines $\frac{1}{2}$ inch apart to represent the thickness of the

washer, and from the elevation project horizontal lines to the sectional view. The corners of this section should be rounded with a radius of $\frac{1}{16}$ inch.

33. Section Lines.—In order to distinguish a sectional drawing without any possibility of mistake, so-called section lines are employed. These are usually made by laying a 45° triangle against the edge of the T square and drawing a series of parallel lines as equally spaced as can be judged by the eye. For cast iron, these lines are full, thin lines, all of the same thickness, and must not be drawn too near together. The method of sectioning for other materials will be given later. It is not customary to draw the section lines in pencil, but to wait until the outlines of the drawing have been inked in and then make the section lines directly with the drawing pen. Section lines should be spaced not less than $\frac{1}{16}$ inch apart, unless, as in Figs. 11 and 12, the drawing is of such small dimensions as to cause a sectioning of this spacing to look coarse. In these two figures, space the section lines a full $\frac{1}{32}$ inch apart. The only parts of the figure to be sectioned are those surfaces that are produced by cutting the ring along the line $p\,q$, both views of the figure being projections on the vertical planes.

34. Views of a Cast-Iron Cylindrical Ring.—Fig. 12 is a cast-iron cylindrical ring. It is shown in elevation and in sectional elevation. The dimensions given suffice for the drawing of the figure without further explanations. The extremities of the diameter of the small circle in the elevation are projected to the sectional side elevation in the points A and B.

35. Inking In of Figures.—The pencil lines showing the construction of the figures of the drawing plate Projections—I are now complete and the entire plate is to be inked in, including the dimension lines and figures. When inking in a drawing, it is generally best to draw the circles and curved lines first and the straight lines last. This enables the draftsman to blend the straight lines into the curved lines so that their points of meeting cannot be detected. Also, tangent lines can be

drawn with better success, and the time for inking in is shortened. It will be noticed that on the drawing plate some of the straight lines are heavy and some light, and that parts of full-line circles are heavy and other parts light. The heavy lines are shade lines, which are described later in this Section. The dotted lines used to indicate the parts of the figures that are hidden must be of the same thickness as the full lines; the construction lines and center lines should be very thin.

36. Dimension figures are to be made $\frac{1}{8}$ inch high and the fractions are to be made $\frac{7}{32}$ inch high. On some of the plates that are to follow there may not be room for figures of this size. In such cases, the figures may be made smaller, but care must be taken to make them *clear*. Until the student has had sufficient practice in lettering, he should draw guide lines in pencil for the dimension figures, as shown in Fig. 44. All the figures should have the same slant of 60°, and, when printing fractional dimensions, the *whole* fraction should have the same slant as the figures; that is, the denominator should not be vertically under the numerator but a little to the left, so that a slanting guide line would pass through the middle of both the numerator and denominator, as shown in the illustration. The dividing line between the numerator and denominator of a fraction is always to be a horizontal line. A slanting division line is never permissible on drawings.

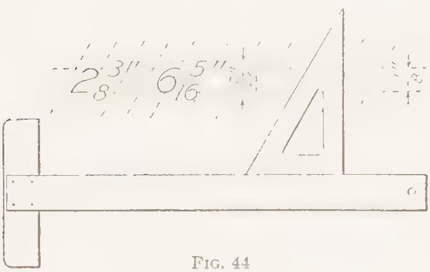


FIG. 44

37. Dimension and extension lines must be light, broken lines of the same thickness as the center and construction lines. Care should be exercised to make the arrowheads as neatly as possible and of a uniform size. They are made with a Gillott's No. 303 pen, or any other fine lettering pen, and their points must touch the extension lines, as illustrated in Fig. 45. Do not make arrowheads too flaring.

When putting in the dimensions, care should be taken to give *all* that would be needed to make the piece which the drawing represents, but usually the same dimensions would not be given on different views. On complicated drawings it is sometimes advisable to duplicate dimensions, as this facilitates the reading of the drawing. In Fig. **1** of the plate, the length is given in the front elevation as 2 inches, and it is obviously unnecessary to give the same dimension in the side elevation. Again, the dimension lines should be put where they would be most likely to be looked for. In Fig. **10** the diameter of the central part of the distance piece is marked $1\frac{1}{4}$ inches in the front elevation; it could have been marked on the side elevation, as the diameter of the dotted circle, but a person wishing to find the size of this part would naturally look for it in the front elevation. This is also true of the diameter of the flange. The diameter of the hole could be on the side elevation or front elevation, but it is put on the side elevation because it is denoted there by a full line, while in the front elevation the hole is shown by dotted lines. The lines of a drawing should never be crossed by dimension lines when possible to avoid it. In Figs. **2** and **4** the $\frac{3}{4}$-inch and in Fig. **3** the 2-inch dimension lines have been placed outside of the figures, thus avoiding crossing the bounding lines of the figures.

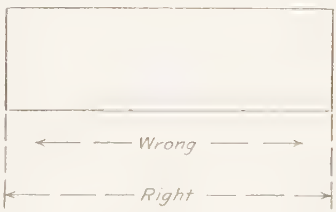


FIG. 45

All the figures used for dimensions shown on this and succeeding plates should be inked in on the drawing, but the letters used to describe the different objects should be omitted. The title should be made in block letters as shown on the sample plate. The date, name, class letters and number are to be put on as in the preceding plates.

DRAWING PLATE, TITLE: PROJECTIONS—II

38. When the surfaces of objects are parallel to the planes on which the views are drawn, the projected views represent the object in its true dimensions. When, however, a machine whose parts are placed at different angles is to be drawn, the projected outlines of the surfaces will not be represented in their true dimensions but will be foreshortened. The figures on the plate Projections—II represent objects similar to those in the preceding plate, but in some instances the surfaces are inclined to the planes of projection, consequently they are not represented in their true dimensions; that is, they appear foreshortened.

39. Rectangular Prism Parallel to the Horizontal Plane but Inclined to All Vertical Planes.—On the preceding plate, Projections—I, the front elevations *A B C D* of Figs. **1**, **2**, and **4** represented outlines true to their dimensions, as the front face *a b c d*, Fig. 37, of the prism in each case was parallel to the front vertical plane.

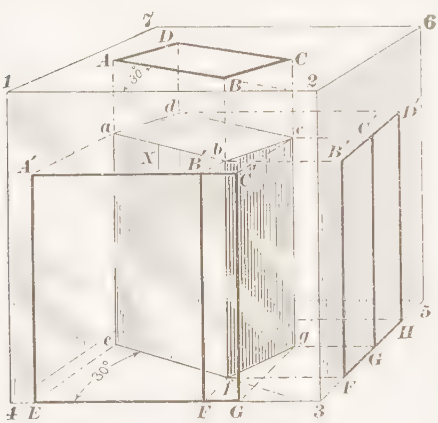


FIG. 46

In Fig. **1** of the plate Projections—II is shown the drawing of a prism whose front and side faces are not parallel to the front and side planes, and consequently are not represented in their true dimensions. The drawing will be better understood by referring to Fig. 46, which shows a prism *X* whose face *a b f e* makes an angle of 30° with the front vertical plane, and consequently its projection on this plane is a foreshortened view. The face *a b c d* of the prism, however, is parallel to the plane *1–2–6–7*, therefore its projection *A B C D*, or plan view, will be in its

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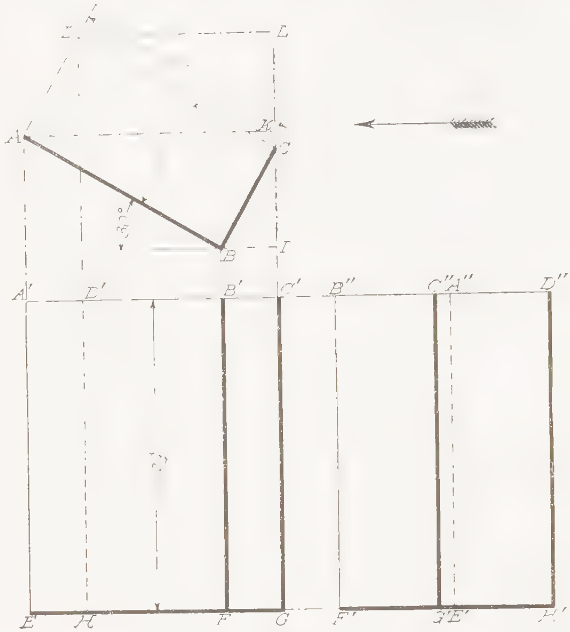

Fig 1

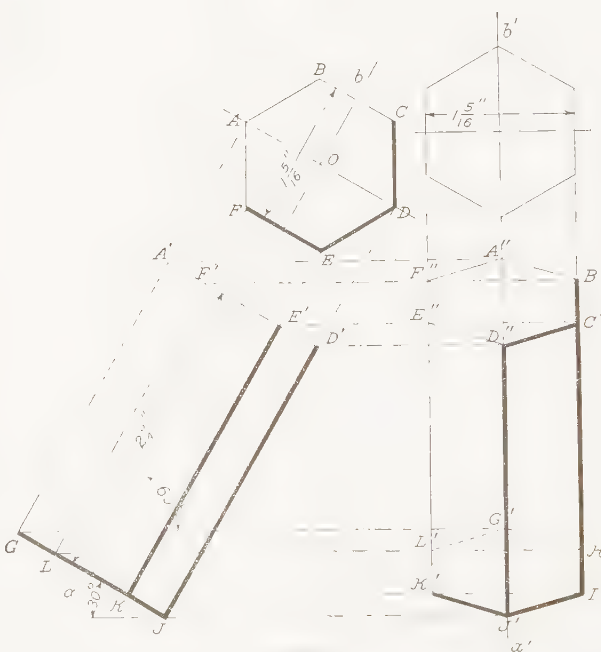

Fig 4

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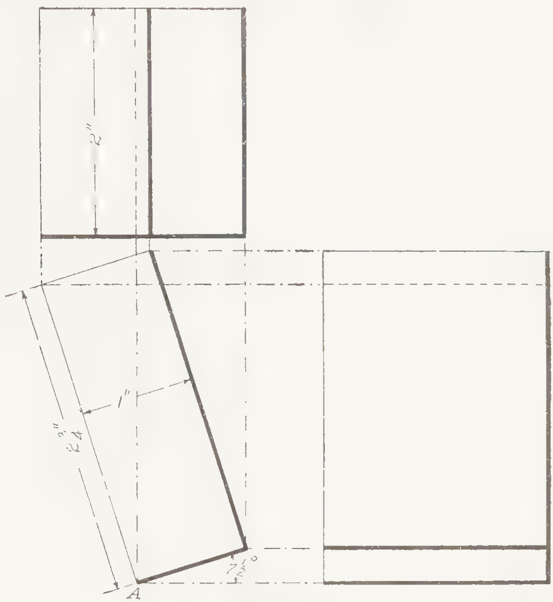
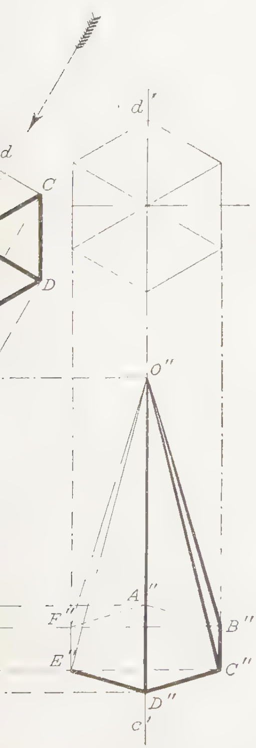


Fig 3.



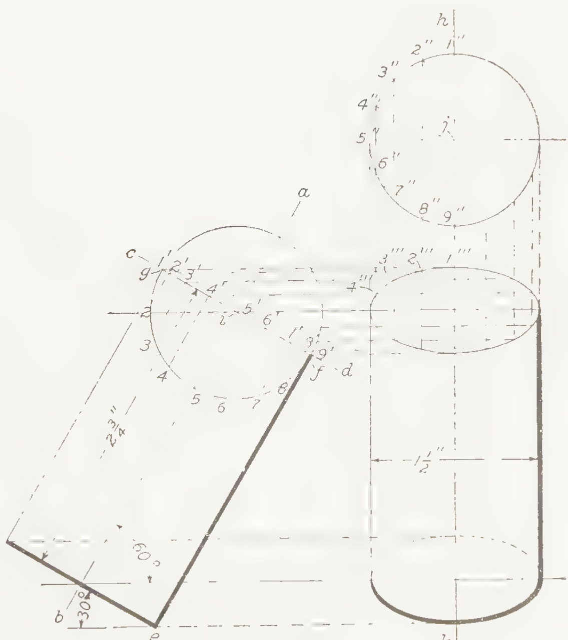


Fig. 5.

true dimensions. The edge line AB will make an angle of 30° with the front vertical plane. Points on the different surfaces of the prism, Fig. 46, are projected to the transparent planes to produce the front and side elevations and the plan view, and when the planes are revolved to one plane the views will occupy the same relative positions shown in Fig. 1, in which the letters on the different views correspond with those on Fig. 46.

The prism is $2\frac{3}{4}$ inches long, 2 inches wide, and 1 inch thick. As the plan view shows true dimensions, this view is drawn first. To draw this view, locate the point B on a horizontal line $2\frac{5}{8}$ inches from the upper border line and $2\frac{1}{2}$ inches from the left-hand border line, then construct a rectangle $ABCD$, $2'' \times 1''$, so that the parallel edges AB and DC make an angle of 30° with the horizontal line as shown. This can be done readily by using a 30° and 60° triangle with the **T** square. From A and B draw AD and BC 1 inch long at right angles to AB and join D and C by a line parallel to AB. Then, $ABCD$ is a rectangle $2'' \times 1''$ and represents the plan, or top view, of the prism.

To construct the front elevation, first draw a horizontal line $5\frac{3}{4}$ inches from the upper border line, as a base line, and $2\frac{3}{4}$ inches above this line draw another horizontal line for the height of the prism. From the corner A of the plan view project a vertical line intersecting the two horizontal guide lines in the points A' and E, and project similar lines from the corners B and C; the lines $A'E$, $B'F$, and $C'G$ thus produced represent the edges of the prism visible in the front elevation. The projection to the point D of the plan view represents an edge that cannot be seen in the front elevation of the prism, therefore it is indicated by a dotted line.

To construct the side elevation, extend the horizontal lines $A'C'$ and EG of the front elevation to the right indefinitely. The widths of the foreshortened surfaces shown in the side elevation are obtained by taking points from the plan view, which is viewed in the direction shown by the arrow. Projectors are drawn with the **T** square from each corner of the plan to intersect a vertical construction line IL, which represents the top edge of the vertical side plane *2–3–5–6*, shown in Fig. 46. The

distances IC and KL are then transferred to the line $A'D''$ with the dividers, thus locating points B'', C'', A'', D'', representing the top edge of the prism in the side elevation. Vertical lines drawn from three of these points to the base line $E H'$ define the visible edges $B'' F'$, $C'' G'$, and $D'' H'$. The dotted line $A'' E'$ represents a hidden edge. This will be more easily seen by viewing the plan in the direction indicated by the arrow.

40. Rectangular Prism Parallel to the Front Vertical Plane but Inclined to the Horizontal and Side Vertical Planes.—The drawing of Fig. **2** is of the same prism as that shown in Fig. **1**, but the prism is assumed to have its broad faces parallel to the front vertical plane and the prism is tipped in such a manner that its base makes an angle of 20° with the horizontal plane. The perspective view of the prism shown in Fig. 47 gives a clearer idea of its position. In this illustration the face $a\,b\,f\,e$ is parallel to the front edge $i\,j$ of the horizontal plane $i\,j\,k\,l$, and the edge $f\,g$ of the prism rests on the surface of the horizontal plane.

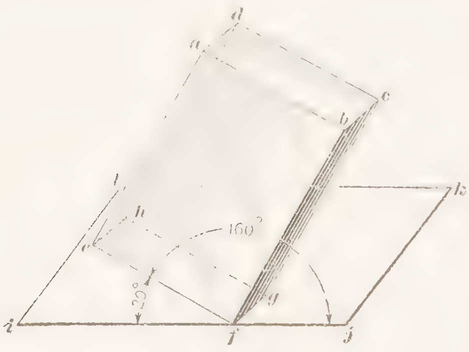


Fig. 47

The front elevation is to be drawn first. This is a rectangle $2\frac{3}{4}$ inches long and 2 inches wide standing with its lower side $B\,A$ inclined at an angle of 20° to the horizontal plane. To draw this view, locate the point A at a distance of $8\frac{1}{4}$ inches from the left border line. From the point A draw a line at an angle of 20°, using a protractor as shown in Fig. 48. On this line locate the point B at a distance of 2 inches, or the width of the prism. At right angles to the line $B\,A$ draw lines of indefinite length, and on these lines measure off $2\frac{3}{4}$ inches, or the height of the prism, locating the points C and D, through which draw a line parallel to $B\,A$.

To construct the plan, draw vertical projection lines from the points *B*, *C*, *A*, and *D* upwards as shown. Across them draw a horizontal line $2\frac{1}{8}$ inches from the upper border line, cutting

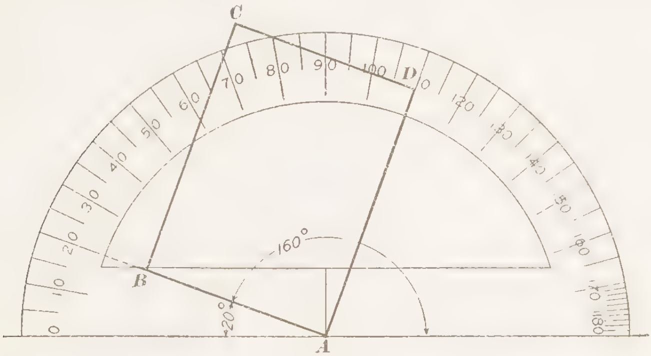


Fig. 48

them in *B′*, *C′*, *A′*, and *D′*, and 1 inch above this draw a second horizontal line cutting them in *E*, *F*, *G*, and *H*. The edge whose projection is *G A′* is the lowest edge of the prism and cannot be seen from above; hence, *G A′* is dotted in the plan.

To construct the side elevation, transfer the measurement, as *D′ H*, from the plan to locate the points *A″* and *G′*, which are 1 inch apart. From *A″ G′* erect two perpendicular lines of indefinite length. Then draw horizontal projection lines from the points *C*, *D*, *B*, and *A* of the front elevation to intersect these vertical lines. The edge *B″E′* is hidden in the side view and is therefore indicated by a dotted line.

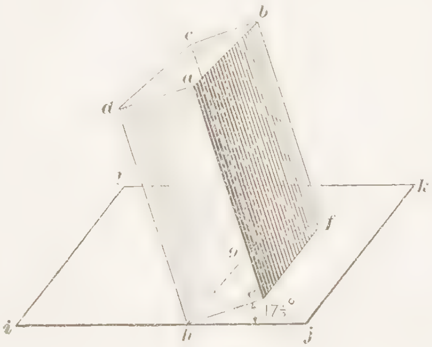


Fig. 49

41. Rectangular Prism Parallel to the Front Vertical Plane but Inclined to the Horizontal and Side Vertical Planes.—The drawing of Fig. 3 is of the same prism as that from which the drawings of Figs. 1 and 2 were

made, but in this case the narrow side of the prism is parallel to the front vertical plane and its base makes an angle of $17\frac{1}{2}°$ with the horizontal. Its position will be more clearly seen from Fig. 49. In this illustration the side $a\,e\,h\,d$ is parallel to the front vertical plane, the broad side $a\,b\,f\,e$ is inclined to the side vertical plane, and the base $g\,f\,e\,h$ is inclined $17\frac{1}{2}°$ to the horizontal.

Draw the front elevation first. This is a rectangle $2\frac{3}{4}$ inches long and 1 inch wide. Locate the corner A on the horizontal guide line $4\frac{3}{8}$ inches from the right border line, construct the rectangle at the required angle, and project the plan view and side elevation from the front elevation. No further explanation is necessary, as the views are constructed in a similar manner to those of Figs. **1** and **2**.

42. Hexagonal Prism Inclined to the Horizontal Plane but Parallel With the Front Vertical Plane.—In Fig. **4** is shown the projections of a hexagonal prism, which is assumed as being parallel to the front vertical plane and as having the base tilted at an angle of 30° with the horizontal plane.

A plan view of the regular hexagon $A\ B\ C\ D\ E\ F$ is to be drawn first. Begin the plan by describing a circle with a radius of $\frac{3}{4}$ inch from a center O located at a point $4\frac{3}{4}$ inches from the lower border line and $3\frac{1}{2}$ inches from the left border line. Through O draw center lines $a\,b$ and $A\,D$ at angles, respectively, of 60° and 30° to the horizontal. Now, with the dividers set to $\frac{3}{4}$ inch, the radius of the circle, lay off the points A, B, C, D, E, F, on the circle for the hexagon, beginning at the point A, and by connecting these points complete the plan view.

Begin the elevation by drawing a horizontal line $\frac{3}{4}$ inch above the lower border line and extend it across the sheet. Next, project a line from the corner D of the plan parallel to the center line $a\,b$ and intersecting the horizontal guide line in the point J. From the point J measure off a distance of $2\frac{3}{4}$ inches on this slanting line, locating the point D', which is the height of the prism. Now, from the points J and D', draw two lines of indefinite length at an angle of 30° with the

horizontal, and from the plan project the corners *A*, *F*, *E*, and *D* to the line *G J* of the elevation, thus producing the edges *A′ G*, *F′ L*, and *E′ K*.

To obtain the side elevation, first draw a series of horizontal projection lines from the points *A′*, *F′*, *E′*, *D′*, *G*, *L*, *K*, and *J*, and extend them to the right indefinitely. Draw a vertical center line *a′ b′* at a distance of $5\frac{1}{16}$ inches from the left border line. Lay off on each side of the center line *a′ b′* a distance of one-half the width of the prism, measured between parallel sides, thus determining the side edge lines *F″ K′* and *B′ I′*. A plan of the prism may be placed on the center line *a′ b′* from which to project the vertical edge lines. Draw the connecting lines *A″ B′*, *A″ F*,″ *D″ E′*, etc., from the intersecting points of the vertical and horizontal projection lines, thus completing the view of the top and bottom surfaces of the prism. Corresponding letters are used in the three views, to assist in the reading. The edges *L′ G′* and *G′ H′* are not visible in the side elevation and are therefore shown by dotted lines.

43. Hexagonal Pyramid Whose Axis Is Inclined but Parallel to the Front Vertical Plane.—In Fig. **5** is shown the projections of a regular hexagonal pyramid whose base is tilted at an angle of 30° with the horizontal plane and whose axis *c d* is parallel to the vertical plane.

The plan, which is a regular hexagon, is constructed about a center *O* located $4\frac{3}{4}$ inches above the lower border line and 8 inches from the right border line in the same manner that the plan of Fig. **4** was constructed. The size of the hexagon and its position is the same as in Fig. **4**. Through the point *O* draw the center line *c d* at an angle of 60° and another center line *A D* at right angles to it. Connect the points *A*, *B*, *C*, *D*, *E*, and *F*, which are the corners of the base, with the center *O* by lines *A O*, *B O*, etc., thus defining the edges of the intersecting side planes, which are foreshortened when the pyramid is viewed in the direction of the arrow.

To draw the front elevation, locate the point *D′* on the guide line at its intersection with a line projected from point *D* of the plan and drawn parallel with the center line *c d*. From this

point D' draw the base line of the pyramid at an angle of 30°, as shown, and project corners A, F, and E from the plan to this base line of the pyramid by lines parallel to the center line $c\,d$. Measure off on the center line $c\,d$ a distance of $2\frac{3}{4}$ inches from the base line $A'\,D'$, thus locating the point O' for the apex of the pyramid. Now, to complete the front elevation, draw lines from the points A', F', E', D' to the point O'.

To construct the side elevation, first locate the vertical center line $c'\,d'$ $6\frac{1}{2}$ inches from the right border line, then from the front elevation draw horizontal lines of indefinite length from the points O', A', F', E', and D' passing through the center line $c'\,d'$. The hexagonal base can be laid off with the dividers from the plan, or the sides may be projected from an auxiliary plan placed in the required position on the center line $c'\,d'$. The lines $F''\,E''$ and $B''\,C''$ representing the parallel sides may now be projected from the plan and the intersecting points E'', D'', C'' and F'', A'', B'' connected by lines, which complete the foreshortened base of the hexagonal pyramid. The elevation is finished by drawing lines from the corners of this base to the apex O''. The dotted lines of the base represent the edges that are not seen.

44. Cylinder Inclined to the Horizontal Plane but Parallel With the Front Vertical Plane.—In Fig. **6** is shown the front and side elevations of a cylinder which is inclined to the horizontal plane at an angle of 30° and is parallel to the vertical plane. The cylinder is $1\frac{1}{2}$ inches in diameter and $2\frac{3}{4}$ inches long. Begin the construction by locating a point i at a distance of $3\frac{1}{2}$ inches above the lower border line and $3\frac{1}{2}$ inches from the right border line. With the bow-pencil set to a radius of $\frac{3}{4}$ inch, describe a circle from the center i for the plan view. Through the point i draw a center line $a\,b$ at an angle of 60° and through the same point draw another center line $c\,d$ at right angles to it, or 30° with the horizontal. From the plan view project two lines from the ends of the diameter on $c\,d$, parallel to the center line $a\,b$, making the line $e\,f$ $2\frac{3}{4}$ inches long, equal to the height of the cylinder, and draw a

line for its base from the point e at an angle of 30°, completing the elevation. The center of the plan of the cylinder has been located to coincide with the top edge of the cylinder in the front elevation for convenience in projecting points to the side elevation.

To draw the side elevation, divide half the circumference of the circle, from g to f, into eight equal parts at 2, 3, 4, etc. From these division points on the circle draw projectors parallel to the center line $a\,b$ to intersect the line $c\,d$, or the top edge of the cylinder, in points $2'$, $3'$, $4'$, etc. Now draw the vertical center line $h\,k$, for the side elevation, $1\frac{1}{2}$ inches from the right border line. On this center line describe another circle, from some point j, to serve as an auxiliary plan from which to project the diameter of the cylinder. Divide the auxiliary plan into sixteen equal parts in points $1''$, $2''$, $3''$, $4''$, etc. Now, from the division points $1'$, $2'$, $3'$, etc. of the front elevation draw horizontal projectors to the right to meet vertical projectors $1''$, $2''$, $3''$, etc. drawn from the auxiliary plan, and where the vertical and horizontal projectors of similar number intersect, locate points through which a curved line is drawn to form an ellipse. In order to avoid confusion, only a few points on the ellipse are numbered. For example, $4'''$ is located in the side elevation where a horizontal projector is drawn from the point $4'$ of the front elevation, intersecting a vertical projector drawn from point $4''$ of the plan view.

Extreme accuracy is necessary in dividing the circles into similar equal parts. The projectors must be drawn exactly from these points of division, otherwise an imperfect ellipse will be formed. The pencil point should be round and sharp for drawing through the points and around an irregular curve. The foreshortened elliptical base is projected similarly to the top.

DRAWING PLATE, TITLE: CONIC SECTIONS

45. Explanation of Conic Sections.—Curves of different shapes are formed by the intersection of a plane with a circular cone or a cylinder. The intersecting plane, sometimes called a **cutting plane,** is imagined to be a flat surface of indefinite extent and without thickness. The surfaces resulting from the intersection of a cutting plane with a cone or a cylinder will have different outlines, according to the inclination, or slope, of the cutting plane. The curves produced by a plane cutting a cone or a cylinder are known as **conic sections,** which, as shown later, may be circles, ellipses, parabolas, or hyperbolas.

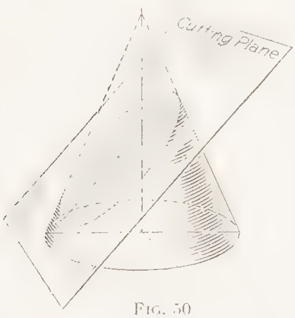


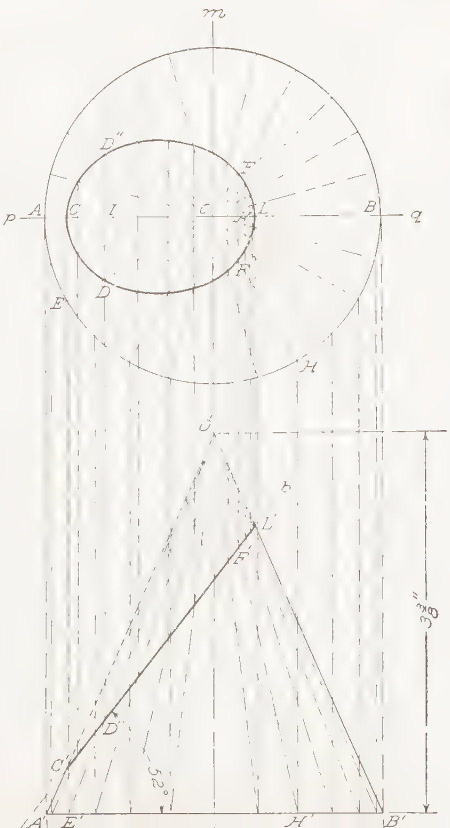
Fig. 50

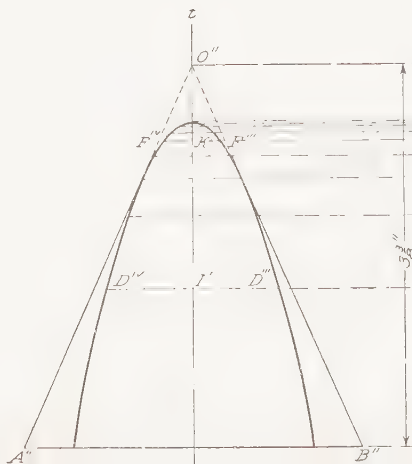
A **right cone** is one having a circular base and its vertex lying on a vertical line, called the axis, perpendicular to the center of the base. A cone with a circular base and having its vertex not perpendicular to the center of the base is called an **oblique circular cone.**

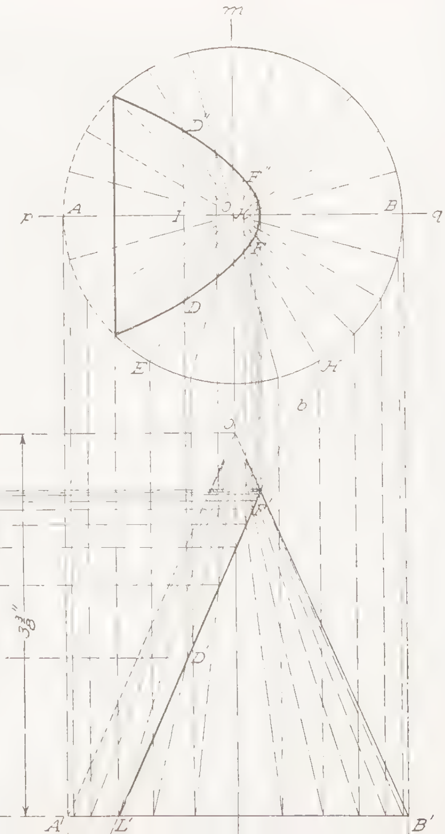
If a right cone is cut by a plane parallel to its base, that is, by a plane perpendicular to the axis, the section is a circle. If the cutting plane is not perpendicular to the axis and cuts off the entire top of the cone, then the section made is an ellipse. Fig. 50 shows how an ellipse is formed in this manner.

46. Conic Section Forming an Ellipse.—In Fig. **1** are shown the projections of a conic section forming an ellipse. In this case the cutting plane $a\,b$ is inclined at an angle of 52° with the base of a right cone $3\frac{3}{8}$ inches high and 3 inches in diameter at the base. To construct Fig. **1**, draw the center line $m\,n$ $2\frac{1}{4}$ inches from the left border line; and at right angles to it draw the center line $p\,q$ at a distance of $2\frac{1}{4}$ inches from the upper border line. Draw a horizontal line of indefinite length for the base of the cone in the elevation. From the point O, with a radius of $1\frac{1}{2}$ inches, describe a circle for the

CONIC SECTIONS.







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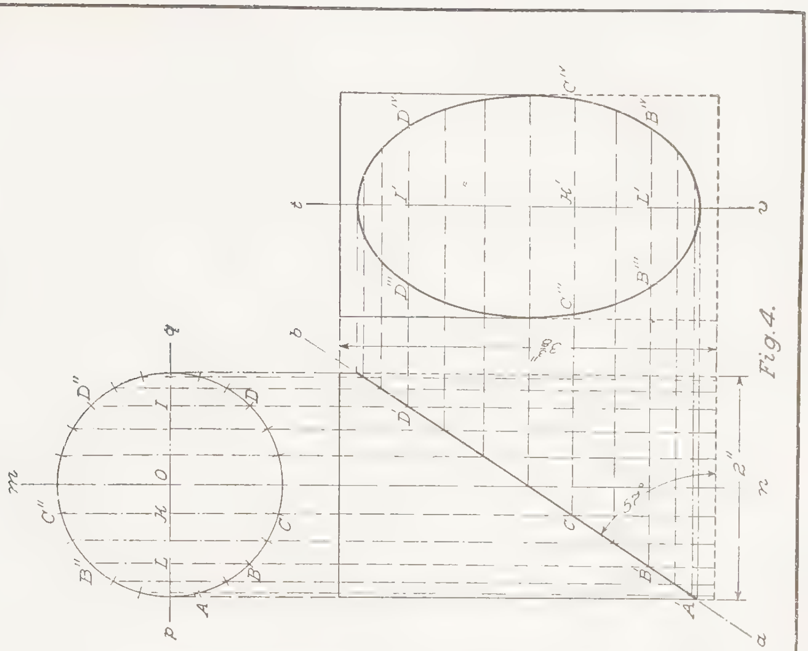

t
v
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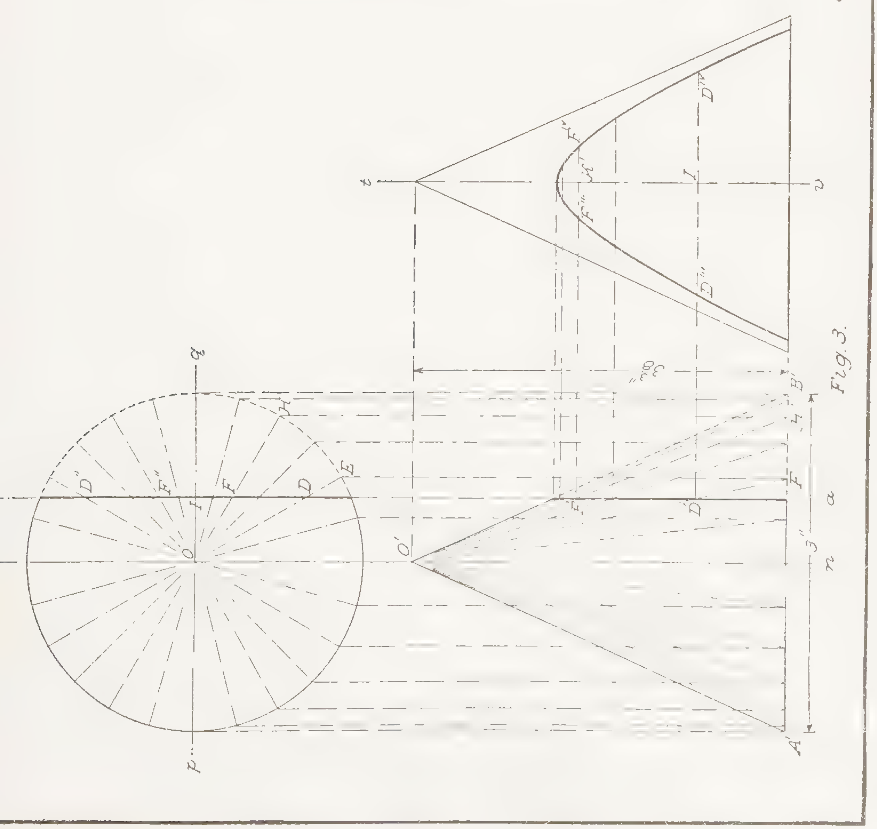
a
b
n
2"
3 1/4"
52°

Fig. 4.



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I
D'''
D^{IV}

Fig. 3.

plan view and from the points A and B on the circumference of this circle draw projectors parallel to the center line $m\ n$ to intersect the base line of the cone in the elevation in points A' and B'. Lay off the vertical height of the cone in the elevation from dimensions given and draw the slanting sides of the cone $A'\ O'$ and $B'\ O'$. The cutting plane is represented in the front elevation by a line $a\ b$ drawn at an angle of 52° to the base, by using a protractor as shown in Fig. 51. Divide the circumference of the circle that represents the plan view into any number of equal parts, in this case 24, and from the points of division A, E, H, etc., draw radial construction lines $A\ O$, $E\ O$, $H\ O$, etc. to the center O. Draw also from these points,

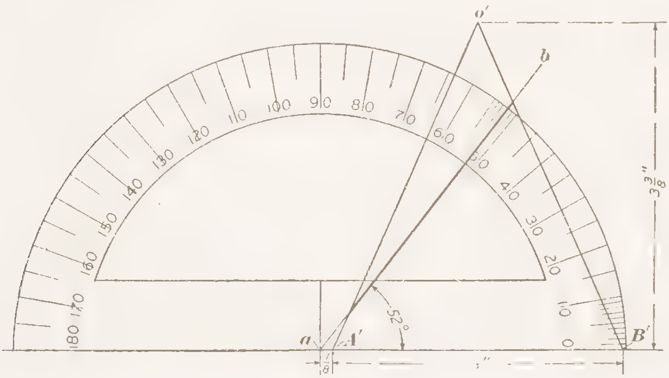


FIG. 51

vertical projection lines, as $A\ A'$, $E\ E'$, $H\ H'$, etc., cutting the base of the front elevation in the points E', H'; etc. From these latter points draw lines to the apex O' of the cone, as $E'\ O'$, $H'\ O'$, etc., cutting the line $a\ b$ in the points D', F', etc. From the points D', F', etc. in the elevation draw to the plan the vertical projecting lines $C'\ C$, $D'\ D\ D''$, $F'\ F\ F''$, $L'\ L$, etc., intersecting the radial construction lines $O\ A$, $O\ E$, $O\ H$, $O\ B$, etc. in the points C, D, F, L, F'', etc. Through these points of intersection draw the ellipse by the aid of an irregular curve. It should be observed that points D, D'' in the plan correspond with the point D' in the elevation, and points F, F'' with the point F'.

It will be noticed that in the drawings on this plate the objects are represented as having been cut through by the plane and a portion removed; only the outlines of the part remaining are shown with full lines, all other outlines being dotted.

47. Section Forming a Parabola.—Fig. 52 shows a cone through which a plane has been passed cutting it at an angle parallel to its slanting side *a b*, or, in other words, parallel to one of its elements and intersecting the base. The curve formed by this intersection is a parabola.

In Fig. 2 the plan and front elevation of the cone are located on the center line *m n* $2\frac{1}{4}$ inches from the right border line, and the curve of intersection in the plan is found by the same method as that used in the preceding problem. To find the side elevation of the intersection, proceed as follows:

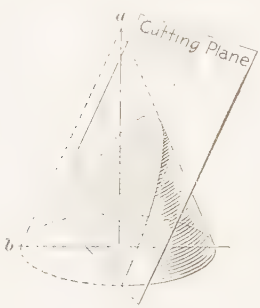


Fig. 52

Draw the side elevation $A'' B'' O''$, which is similar in form to the front elevation, with the center line *t v* as its axis $5\frac{1}{4}$ inches from the right border line. Draw horizontal projection lines from D', F', etc. of the front elevation to intersect the center line *t v* of the side elevation in K' I', etc. With the dividers, transfer the distance $I\ D$, $I\ D''$, etc., from the plan to the side elevation as $I'\ D'''$ and $I'\ D^{iv}$, also transfer $K\ F$ and $K\ F''$ from the plan to the side elevation as $K'\ F'''$ and $K'\ F^{iv}$, thus locating points D''' and D^{iv} and F''' and F^{iv}. In the same way other distances may be transferred and other points located, and a curve may be traced through them. The result will be the side elevation of the cone when cut by a plane parallel to one of its elements. A side elevation of Fig. 1 may be drawn similarly.

48. Conic Section Forming a Hyperbola.—Fig. 53 shows a perspective view of a cone with the cutting plane parallel to its axis. When the cutting plane intersects the base of a cone and is not parallel to any element, the curve of intersection is called a hyperbola.

In Fig. **3** the cone has the same dimensions as in the two preceding problems, and the plan and the front elevation are constructed as before. The projection of the curve in the plan in this particular case, where the cutting plane is parallel to the axis of the cone, is a straight line $a\,b$ in the plan and in the front elevation. The side elevation is found, as in the last problem, by drawing horizontal projection lines from F', D' of the elevation to intersect the center line $t\,v$ of the side elevation. With the dividers, transfer from the plan the distances $I\,D$ and $I\,D''$ to the side elevation as $I'\,D'''$ and $I'\,D^{iv}$, also transfer $I\,F$ and $I\,F''$ to $K'F'''$ and $K'\,F^{iv}$ of the side elevation, thus locating points D''', D^{iv}, F''', F^{iv}. In the same way, other distances may be transferred and other points located through which a curve may be drawn to obtain the required hyperbola.

FIG. 53

49. Oblique Section of a Cylinder.—A plane cutting a cylinder at an angle to the axis will produce an ellipse, as shown in Fig. 54. In Fig. **4** is shown the method of determining the ellipse in the side elevation in this case. The cylinder is 2 inches in diameter and $3\frac{3}{8}$ inches long and cut by a plane $a\,b$ making an angle of 57° with the base. Begin by drawing a center line $m\,n$ at $4\frac{1}{4}$ inches from the right border line; and at right angles to it draw the center line $p\,q$ $5\frac{5}{8}$ inches from lower border line. From the point O with a radius of 1 inch, or one-half the diameter of the cylinder, describe a circle for the plan view. Construct the front and the side elevation as already explained, the horizontal projection or plan being a circle having the same diameter as the

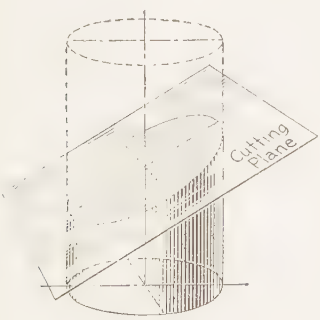


FIG. 54

base. Construct the front elevation from the dimensions given and draw the line *a b* at an angle of 57° to represent the cutting plane.

Draw the side elevation of the cylinder, which is similar in form to the front elevation. To construct the side elevation of the curve, divide the circumference of the circle representing the plan of the cylinder into any number of equal parts, in this case 24, and through the points of division, as *A*, *B*, *C*, etc., draw vertical projection lines as shown. These will cut *a b* in the points A', B', C', D', etc., and horizontal lines are projected from these points to intersect the center line *t v* in the side elevation. This center line is located $1\frac{3}{4}$ inches from the right border line. Then with the dividers transfer from the plan the distances LB, LB''; KC, KC''; ID, ID'', etc. to the side elevation and from the points L', K', I' on the center line *t v* locate the points B''', B^{iv}, C''', C^{iv}, D''', and D^{iv} of the required ellipse. Other points may be transferred and located in like manner, and a smooth curve drawn through the points thus located will be the required side elevation.

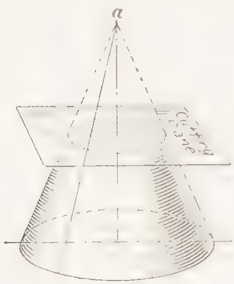


Fig. 55

50. Sections Which Form Circles. When a right cone is cut by a plane parallel to the base of the cone, the resulting section is a circle, as shown in Fig. 55. Its diameter depends on the distance of the cutting plane from the vertex *a* of the cone. If a cone is cut by a plane through its vertical axis, the resulting section will be an isosceles triangle, as shown in Fig. 56, its outline being the same shape as the front elevation.

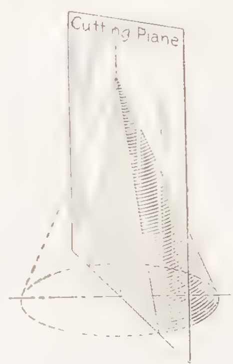


Fig. 56

CONVERTING DECIMALS INTO COMMON FRACTIONS

51. On the next plate some dimensions are given in decimal fractions instead of common fractions. Such decimal dimensions are best laid off with a **decimal scale,** which is a scale with inches divided into tenths, hundredths, etc. Such a scale is not essential for this work, however, and the nearest value of the decimal fraction may be taken in thirty-seconds of an inch.

To change a *decimal fraction* to a *common fraction* having a desired denominator, multiply the decimal by the desired denominator of the common fraction, and express the result as a whole number, which whole number will be the numerator of the fraction.

Thus, to express .765 inch in fourths, we have $.765 \times 4 = 3.06$; placing this product over 4 as a denominator, the result is $\frac{3.06}{4}$ or, say, $\frac{3}{4}$ inch.

To express .765 in thirty-seconds, $.765 \times 32 = 24.48$; with 32 as denominator the result is $\frac{24.48}{32}$ or, say, $\frac{24}{32}$ inch.

If, after multiplying, the decimal part of the product equals .5 or over, drop it and add 1 to the whole number. Thus, in changing a decimal fraction of .66 inch to a common fraction having 16 as a denominator, the result is $.66 \times 16 = \frac{10.56}{16}$, or, say, $\frac{11}{16}$ inch.

The circumference of a circle is equal to the diameter multiplied by 3.1416. Thus, the circumference of a circle with a diameter of $1\frac{3}{8}$ inches is $3.1416 \times 1\frac{3}{8} = 4.32$ inches, or, say, $4\frac{5}{16}$ inches.

The circumference of a circle whose diameter is $1\frac{1}{2}$ inches is $3.1416 \times 1\frac{1}{2} = 4.71 = 4\frac{23}{32}$ inches.

The circumference of a circle whose diameter is $1\frac{1}{4}$ inches is $3.1416 \times 1\frac{1}{4}$ inches $= 3.93$, or, say, $3\frac{15}{16}$ inches.

52. Decimal Equivalents.—Decimal equivalents for the fractions most commonly used by mechanics are given in the

following table. Since the results obtained in calculations are usually decimal quantities, it is desirable that a convenient means should be afforded for their conversion into ordinary fractions. By the aid of this table any decimal may be readily resolved into its corresponding fraction or into a fraction that approaches its real value nearly enough for all practical purposes.

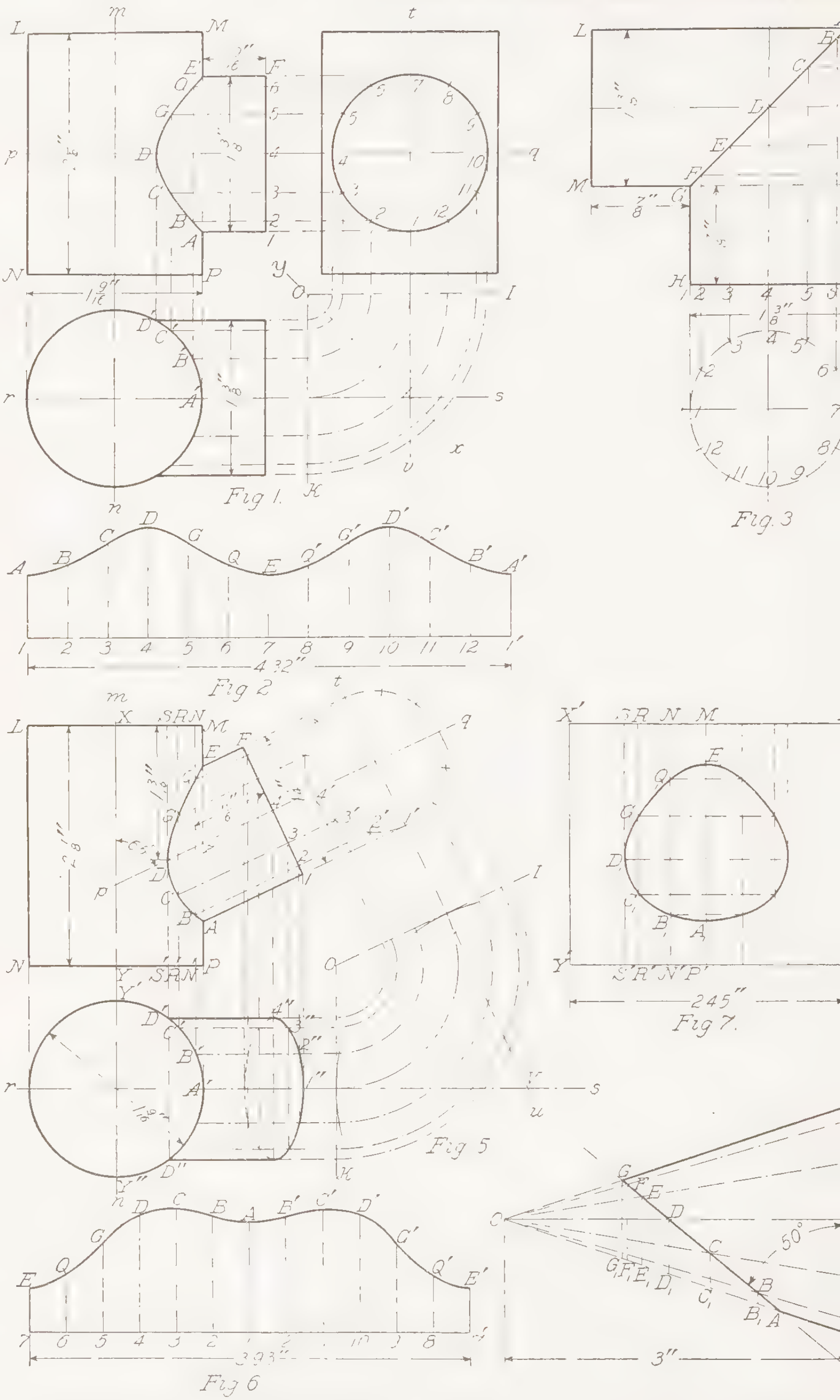
8ths	$\frac{1}{8}=.125$
	$\frac{1}{4}=.25$
	$\frac{3}{8}=.375$
	$\frac{1}{2}=.5$
	$\frac{5}{8}=.625$
	$\frac{3}{4}=.75$
	$\frac{7}{8}=.875$

16ths	$\frac{1}{16}=.0625$
	$\frac{3}{16}=.1875$
	$\frac{5}{16}=.3125$
	$\frac{7}{16}=.4375$
	$\frac{9}{16}=.5625$
	$\frac{11}{16}=.6875$
	$\frac{13}{16}=.8125$
	$\frac{15}{16}=.9375$

32ds	$\frac{1}{32}=.03125$
	$\frac{3}{32}=.09375$
	$\frac{5}{32}=.15625$
	$\frac{7}{32}=.21875$
	$\frac{9}{32}=.28125$
	$\frac{11}{32}=.34375$
	$\frac{13}{32}=.40625$
	$\frac{15}{32}=.46875$
	$\frac{17}{32}=.53125$
	$\frac{19}{32}=.59375$
	$\frac{21}{32}=.65625$
	$\frac{23}{32}=.71875$
	$\frac{25}{32}=.78125$
	$\frac{27}{32}=.84375$
	$\frac{29}{32}=.90625$
	$\frac{31}{32}=.96875$

64ths	$\frac{1}{64}=.015625$
	$\frac{3}{64}=.046875$
	$\frac{5}{64}=.078125$
	$\frac{7}{64}=.109375$
	$\frac{9}{64}=.140625$
	$\frac{11}{64}=.171875$
	$\frac{13}{64}=.203125$
	$\frac{15}{64}=.234375$
	$\frac{17}{64}=.265625$
	$\frac{19}{64}=.296875$
	$\frac{21}{64}=.328125$
	$\frac{23}{64}=.359375$
	$\frac{25}{64}=.390625$
	$\frac{27}{64}=.421875$
	$\frac{29}{64}=.453125$
	$\frac{31}{64}=.484375$
	$\frac{33}{64}=.515625$
	$\frac{35}{64}=.546875$
	$\frac{37}{64}=.578125$
	$\frac{39}{64}=.609375$
	$\frac{41}{64}=.640625$
	$\frac{43}{64}=.671875$
	$\frac{45}{64}=.703125$
	$\frac{47}{64}=.734375$
	$\frac{49}{64}=.765625$
	$\frac{51}{64}=.796875$
	$\frac{53}{64}=.828125$
	$\frac{55}{64}=.859375$
	$\frac{57}{64}=.890625$
	$\frac{59}{64}=.921875$
	$\frac{61}{64}=.953125$
	$\frac{63}{64}=.984375$

INTERSECTIONS



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EVELOPMENTS.

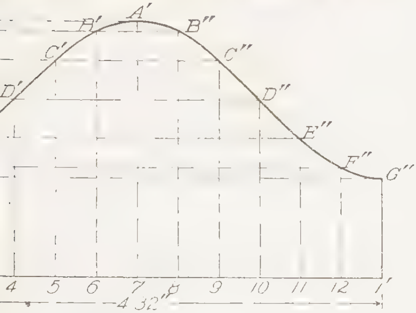


Fig 4

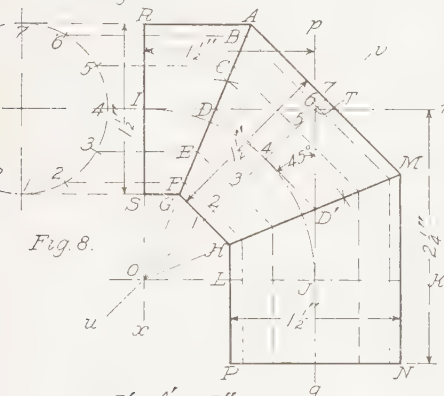


Fig.8.

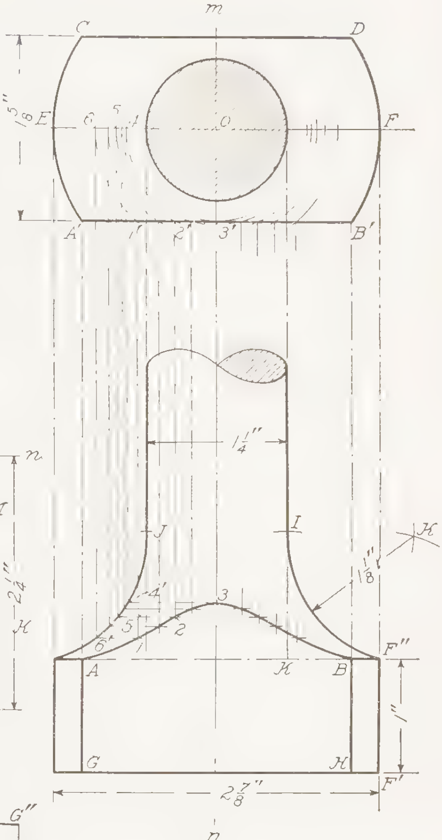


Fig.10.

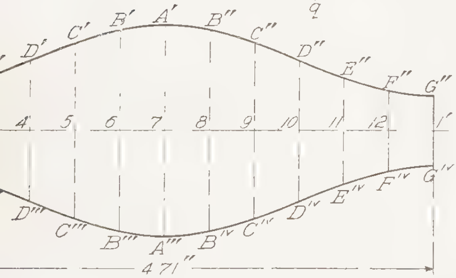
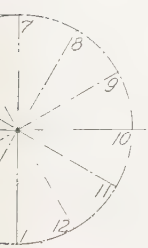


Fig. 9.



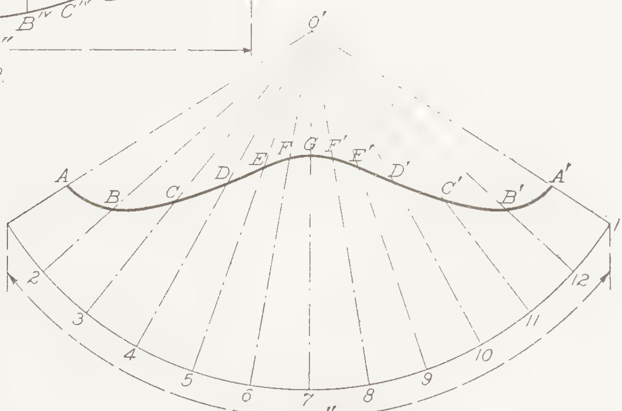


Fig.12.

DRAWING PLATE, TITLE: INTERSECTIONS AND DEVELOPMENTS

53. The drawing plate Intersections and Developments now to be taken up deals with the intersections of the surfaces of solids and the method of obtaining the miter line, as it is commonly called. By the methods explained in connection with this plate the patterns of the intersected surfaces may be developed. One of the important requirements in the construction of these figures is to locate with accuracy the points lying in the line of intersection.

54. Intersection of Two Unequal Cylinders at Right Angles.—Fig. 57 shows a perspective view of two cylinders of different diameters intersecting at right angles to each other. Fig. **1** shows a plan and a front and a side elevation of the object.

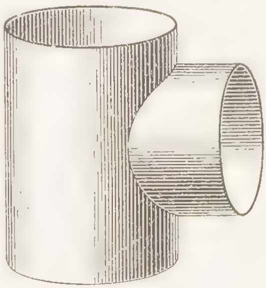


Fig. 57

To draw the views shown in Fig. **1**, first locate the axis, or center line *m n*, of the larger cylinder $1\frac{1}{2}$ inches from the left border line. Next draw the horizontal center line *p q* of the small cylinder $1\frac{15}{16}$ inches from the upper border line.

On these center lines, with the dimensions given in the figure, draw a front elevation consisting of the outline *1 A P N L M E F*. The curve *A B C D G Q E*, of course, cannot be drawn yet, as the points through which the curve is to be drawn are still to be determined.

Below the front elevation, draw the plan located on a center line *r s* $4\frac{1}{8}$ inches from the upper border line. To the right of the front elevation draw the side elevation as shown, locating it on a vertical center line *t u* $4\frac{1}{8}$ inches from the left border line. At the intersection of *p q* and *t v*, describe a circle representing the smaller cylinder, and complete the side elevation. Divide the circle in the side elevation into 12 equal parts and from points of division *1*, *2*, *3*, *4*, etc. project horizontal

lines to the front elevation. The points of division *1*, *2*, *3*, *4*, etc. of the circle in the side elevation are to be transferred to the plan view, in the following manner:

Through the point of intersection of the center lines $t v$ and $r s$ draw a line $x y$ at an angle of 45°. Then draw horizontal and vertical construction lines $O I$ and $O K$ so that they will intersect on the line $x y$ at a convenient point, as O.

The points of division on the circle in the side elevation may now be projected to the line $O I$ and then each point is to be revolved to the vertical line $O K$, O being used as a center. From the points on the line $O K$, extend projectors to intersect the large cylinder in points A', B', C', and D' in the plan view. From these points in the plan view, draw vertical projectors that will intersect the projectors *1*, *2*, *3*, *4*, etc. drawn from the side elevation, in points A, B, C, D, etc., through which a curve may be drawn to represent the required intersection of the two cylindrical surfaces; this completes the front elevation. There is, of course, a similar curve from E to A on that part of the object hidden from view.

55. If the part *1* A D E F were assumed to be of thin sheet metal, and if it were cut along the line *1* A and laid out on a flat surface, it would have the form shown in Fig. **2**, and this figure would be termed the **development** of the cylindrical part *1* A D E F.

To determine the form and size of this development, draw a horizontal line $6\frac{1}{4}$ inches from the upper border line, and on this line lay off a distance *1–1′*, Fig. **2**, equal in length to 4.32 inches, which is the circumference of the circle shown in the side elevation of Fig. **1** and this circle is the projection of the cylindrical part in question.

Divide the distance *1–1′*, Fig. **2**, into as many equal parts as were used in dividing the circle, in this case twelve, and at these points of division erect perpendiculars to the horizontal line *1–1′*. Then with the dividers measure off the distances *1* 4, *7* E, and *1′* A' each equal to *1* A in the front elevation; *2* B, *6* Q, *8* Q' and *12* B' equal to *2* B in the elevation; *3* C, *5* G, *9* G', *11* C' equal to *3* C; and *4* D and *10* D' equal to *4* D

of the elevation. A smooth curve drawn through the points *A*, *B*, *C*, etc. thus found will complete the development.

The form of this development is such that if it were cut out along its bounding line and bent into cylindrical form and joined along the edges *1 A* and *1′ A′*, its irregular edge would fit snugly to the large cylinder as indicated in the front elevation in Fig. **1**.

56. Intersection of Two Equal Cylinders at Right Angles.—In Fig. 58 is shown an elbow that consists of two cylinders intersecting each other at right angles. By referring to Fig. **3** it is seen that the lines of intersection between cylinders equal in diameter and intersecting each other in the same plane, so that their axes also intersect, are always represented by straight lines in a view that shows the axes in their true length. Thus, in Fig. **3**, the projection of the line of intersection is the straight line *A G*.

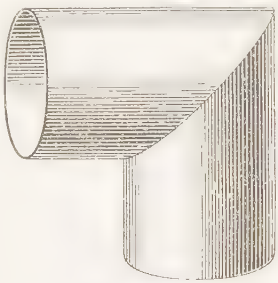


Fig. 58

To obtain the development of the cylindrical part *A G H K*, proceed as follows:

Begin by drawing the front elevation from the dimensions given, locating the horizontal axis $1\frac{9}{16}$ inches from the upper border line and the vertical axis $7\frac{5}{16}$ inches from the left border line. On these axes, draw two cylinders $1\frac{3}{8}$ inches in diameter, and through the intersection of their axes, as at *D*, draw a line at an angle of 45°. From the point *G* measure off distances *G H* and *G M* equal to $\frac{7}{8}$ inch, which determines the length of each cylinder. This completes the elevation.

On the vertical center line below the elevation draw a dotted circle to represent the plan. Divide the circle into a number of equal parts, in this case twelve, and from the points of division draw vertical projection lines to meet *A G* at *B*, *C*, etc. Extend the line *H K* indefinitely to the right to form the base line of the development, Fig. **4**, and on the extended part set off a distance *1–1′* equal to 4.32 inches, the circumference of

the dotted circle. Divide this distance into twelve equal parts, also, and erect perpendiculars to the line *1–1′* from the points of division. From *A, B, C*, etc., Fig. **3**, draw horizontal projection lines intersecting the perpendiculars in Fig. **4** in *A′, B′, B″, C′, C″*, etc., and through the points *A′, B′, C′*, etc. thus found draw a smooth curve. The resulting figure is the required development. Since the part *A G M L* is exactly like *A G H K*, its development is the same as in Fig. **4**. Hence, if two flat thin plates were cut to the same shape and size as this development and each were rolled into true cylindrical form with the edges *1 G′* and *1′ G″* coinciding, they could be put together as shown in the front elevation and the slanting edges would fit accurately at all points.

57. Intersection of Two Unequal Cylinders at an Angle of 65°.—Fig. 59 is an illustration of two cylinders of unequal diameters joining each other at an angle of 65° instead of 90° as in Fig. **1**. It is desired to determine the curve of intersection of the two cylinders in the front elevation. The method of doing this is shown in Fig. **5**.

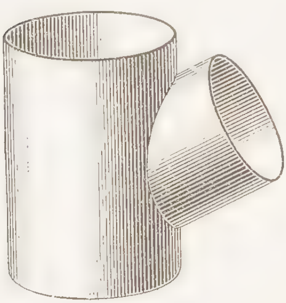


FIG. 59

Begin by locating a vertical center line *m n* $1\frac{1}{2}$ inches from the left border line, and draw a front elevation of the cylinder *L M P N* $1\frac{9}{16}$ inches diameter and $2\frac{1}{8}$ inches long, locating the base line $3\frac{7}{8}$ inches from the lower border line. Below the elevation draw a horizontal center line *r s*, $2\frac{3}{4}$ inches from the lower border line, to intersect the center line *m n*, at which intersection describe a circle $1\frac{9}{16}$ inches in diameter. Draw two horizontal lines of indefinite length $\frac{5}{8}$ inch each side of the center line *r s*, intersecting the circle in *D′* and *D″* in the plan. Project a vertical line from *D′ D″* to intersect the elevation in *S′ S*, and on this line locate point *D* $1\frac{3}{16}$ inches from the line *L M*. By use of a protractor, a center line *p q* for the inclined cylinder may now be drawn from point *D* at an angle of 65° with the axis *m n*. On the

line $p\,q$, measure off $\frac{11}{16}$ inch from the point z and draw line $F\,1$. Two lines drawn from E and A parallel to $p\,q$ complete the elevation, except the curve of intersection, which is projected from the plan view and the dotted circle in the same manner as described for Fig. **1**. The only difference lies in locating the point O from which the projectors are revolved from the dotted circle to the plan view.

To locate the construction lines $O\,I$ and $O\,K$, proceed as follows: At right angles to $p\,q$ draw a center line $t\,u$ to intersect the horizontal center line $r\,s$, thus locating a point V. With the point V as a center, describe two short arcs cutting the center lines $r\,s$ and $t\,u$, and tangent to these arcs draw construction lines $O\,I$ and $O\,K$ parallel to $p\,q$ and $m\,n$, respectively, to intersect in point O. The points of division from the dotted circle may now be projected to the line $O\,I$, and with O as a center the projection lines can be revolved to intersect the line $O\,K$ and then be extended to the plan view. The ellipse in the plan view is the projection of the inclined end of the small cylinder in the front elevation, and its outline is determined by the method used in connection with Fig. **6** of the plate Projections—II.

58. The development of the pattern for the smaller cylinder of Fig. **5** is shown in Fig. **6**. To draw it, measure off on a horizontal line the distance 7–$7'$ equal to 3.93 inches, equal to the circumference of the dotted circle in Fig. **5**. Divide 7–$7'$ into twelve equal parts as was the circle, and erect perpendiculars. It is assumed that the cylinder is cut along the line $E\,F$ in the elevation in Fig. **5** and therefore in the development of this part it will be the smallest vertical distance to be measured off.

Begin at the middle point $1\,A$ by making the vertical distance $1\,A$ in the development equal to $1\,A$ of the elevation. Measure off the vertical distances $2\,B$, $12\,B'$, $3\,C$, $11\,C'$, etc., equal, respectively, to the distances $2\,B$, $3\,C$, etc. of Fig. **5**. Continue this until the two ends are reached in $7\,E$ and $7'\,E'$. Trace a smooth curve through the points thus found, and the resulting figure is the required development. The development

of the larger cylinder will have a hole of a certain shape due to the small cylinder intersecting it at an angle.

59. Fig. **7** represents the development of the large cylinder shown in Fig. **5** and is obtained as follows: Extend the lines $L M$ and $N P$ of the elevation indefinitely to the right to indicate the height of the large cylinder in the development. At a distance of $5\frac{1}{2}$ inches from the left border line draw a vertical line intersecting the two extended lines in points X' and Y'. From Y' measure to the right a distance equal to 2.45 inches, locating Y'', and at this point erect a perpendicular to intersect the horizontal line in X''. The horizontal distance $Y' Y''$ of Fig. **7** must be taken from the plan, Fig. **5**, and is the distance $Y' A' Y''$, which is seen to be one-half the circumference of the circle. Therefore, the rectangle $X' X'' Y'' Y'$ is equal to one-half the surface of the cylinder of which the circle is the plan.

Next, at the middle point P' of the line $Y' Y''$, erect a perpendicular $P' M$. From the circle in the plan, with the dividers, measure off the chord distance $A' B'$ and transfer this distance along the line $Y' Y''$, beginning at P', and locate the point N'. The distances $B' C'$ and $C' D'$ of the plan are transferred successively in the same manner, locating points R' and S' on the line $Y' Y''$. Erect perpendiculars at these points to intersect the line $X' X''$ in points N, R, and S. Next, by the use of the **T** square, from the points A, B, C, D, etc., of the elevation in Fig. **5**, project construction lines to intersect the perpendiculars $P' M$, $N' N$, etc., thus locating points A_1, B_1, C_1, etc. If it is desired, these points may be transferred from the elevation with dividers; for example, the distance $P A$ in the elevation will equal $P' A_1$ in the development, and $N' B$, $R' C$, and $S' D$, etc. in the elevation will equal $N' B_1$, $R' C_1$, $S' D_1$, etc. in Fig. **7**. The points A_1, B_1, C_1, etc. having thus been located, similar points to the right of the center line $P' M$ are located by the intersection of the same projected horizontal lines and verticals located from the elevation in a manner similar to that employed for locating $N' N$, $R' R$, etc. A smooth curve may be drawn through the points thus found

and the resulting outline will be the development of the line of intersection of the large cylinder.

If the pattern were cut of the same size and shape as shown in Fig. **7** and rolled to a semicylindrical form, the edges of the opening would coincide with the edges of a cylinder whose development is shown in Fig. **6**.

60. Development of Middle Section of Three-Piece Elbow.—Fig. 60 shows a perspective view of an elbow composed of three cylinders of the same diameter and connected so that the two end sections are at right angles to each other.

The diameter of each of the cylinders is $1\frac{1}{2}$ inches. To construct the elevation shown in Fig. **8**, draw a horizontal center line $m\,n$ $4\frac{9}{16}$ inches from the upper border line, and at right angles to it draw a center line $p\,q$ 5 inches from the right border line.

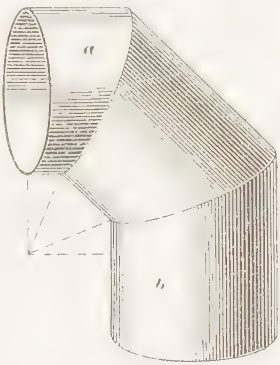


FIG. 60

Where these two center lines intersect in T draw a center line $u\,v$ at an angle of 45°. At a distance of $1\frac{1}{2}$ inches to the left of the center line $p\,q$ draw a vertical line $R\,x$ of indefinite length intersecting the line $u\,v$ in the point O.

From the point O, draw a horizontal line $O\,K$ of indefinite length, and with O as a center and the pencil compasses set to a radius of $1\frac{1}{2}$ inches, describe an arc from I to J.

To determine the joint, or miter, lines $A\,G$ and $M\,H$, bisect the arcs $I\,4$ and $4\,J$ by setting the compasses to any convenient radius and describing short arcs from centers 4 and I, also from 4 and J, and through the intersections of the arcs draw lines $O\,A$ and $O\,M$. Now, on the center line $m\,n$, draw a circle with a radius of $\frac{3}{4}$ inch to represent an end view. From the ends of its diameter project two horizontal lines $R\,A$ and $S\,G$ in the elevation. The point D is located where the center line $m\,n$ intersects the line $O\,A$, and from this point a center line for the middle section may be drawn at an angle of 45°

intersecting the line *O M* in *D′*, and two lines *A M* and *G H* representing the outside of the cylinder are drawn parallel to it. The vertical cylinder section may now be drawn by locating the horizontal line *P N* $2\frac{1}{4}$ inches below the center line *m n*. The two vertical lines *H P* and *M N* are now drawn, completing the elevation.

61. In Fig. **9** is shown the development of the middle section *A G H M* of Fig. **8.** First divide the dotted circle, Fig. **8,** into twelve equal parts and project the points of division to the elevation to intersect the joint line *A G*, thus fixing the points *A*, *B*, *C*, *D*, *E*, etc., and from these points draw lines across the section *A G H M* parallel to the center line *D D′*, or, in other words, at right angles to the center line *u v*. Where the points of division cross the center line *u v* locate points *1*, *2*, *3*, *4*, etc.

Then, in Fig. **9,** draw a horizontal line $4\frac{7}{8}$ inches from the lower border line and on this line measure off a distance *1–1′* equal in length to the circumference of the dotted circle in Fig. **8,** which is 4.71 inches. Divide this length into twelve equal parts corresponding to the twelve equal parts into which the dotted circle in Fig. **8** is divided and draw vertical lines through the points of division. Assume that the joint of the middle section is at *G H* in Fig. **8.** Then in Fig. **9** make *1 G′* and *1′ G″* equal to *1 G*, Fig. **8**; and *2 F′* and *12 F″* equal to *2 F*; *3 E′* and *11 E″* equal to *3 E*; *4 D′* and *10 D″* equal to *4 D*; *5 C′* and *9 C″* equal to *5 C*; *6 B′* and *8 B″* equal to *6 B*; and *7 A′* equal to *7 A*.

A curve through the points *G′*, *F′*, *E′*, *D′*, etc. gives the outline of the upper half of the development. The other half of the curve below the line *1–1′* is of exactly the same shape, and is obtained by transferring the points with the dividers.

62. Curve of Intersection of Flattened Rod.—In Fig. 61 is illustrated a cylindrical rod that is enlarged at the one end, and the sides have been flattened, thus making two parallel faces intersecting a curved surface, and producing a curved line. It is desired to find the exact form of the curve. Fig. **10** shows how this may be done.

The object is a cylindrical rod $1\frac{1}{4}$ inches in diameter and the extreme end has been enlarged to a diameter of $2\frac{7}{8}$ inches. The two parallel faces, as shown in the plan, are $1\frac{5}{8}$ inches apart. It is desired to find the exact form of the curve $A\ 3\ B$ representing the intersection of one of the flat surfaces with the curved surface, as shown in the elevation.

First draw a vertical center line $m\ n$ $2\frac{3}{16}$ inches from the right border line, and at right angles to it draw a horizontal center line $E\ F$, $1\frac{11}{16}$ inches from the upper border line, intersecting at O, from which point describe a circle with a $\frac{5}{8}$-inch radius to represent a top view of the rod, which is section-lined to indicate that it is broken. Another circle is described from the center O with a radius of $1\frac{7}{16}$ inches for the large diameter. The two flat faces are represented by two horizontal lines $C\ D$ and $A'\ B'$ drawn at a distance of $\frac{13}{16}$ inch above and below the center line $E\ F$, thus completing the plan.

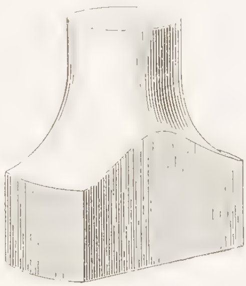


FIG. 61

Begin the elevation by drawing a base line $7\frac{3}{8}$ inches from the upper border line. From the points E and F of the plan, draw vertical lines to intersect the base line of the elevation in points $E'\ F'$. Also project $A'\ B'$ from the plan to intersect the base line in points G and H. Measure off a vertical distance of 1 inch from the base line $E'\ F'$ and draw an indefinite horizontal line. Vertical lines drawn from the base line from points E', G, H, and F' will intersect this horizontal line in points E'', A, B, and F''. From the circle in the plan, project two lines for the diameter of the $1\frac{1}{4}$-inch rod in the elevation, and connect it to the enlarged end at the base by arcs $J\ E''$ and $I\ F''$. The arc $I\ F''$ is drawn tangent to the rod with a radius of $1\frac{1}{8}$ inches; the center from which the arc is described is located as follows: Extend the line representing the diameter of the rod to intersect the horizontal line $E''\ F''$ in the point K. With compasses set to a radius of $1\frac{1}{8}$ inches describe a short arc from the point K, cutting the vertical line in I. With the compasses kept to the same radius, describe short arcs

with I and F'' as centers and intersecting in K', from which point the arc $I F''$ can be described tangent to the rod and touching the point F''. The arc $J E''$ may be drawn in a similar manner.

This completes the elevation, except the curve $A\ 3\ B$, which is yet to be determined.

63. Now, with O as a center and radii of suitable lengths, describe arcs cutting the line $A'\ B'$ in several points, as $1'$, $2'$, $3'$, etc., and continue these arcs until they intersect the horizontal line $E\ F$, thus giving the points 4, 5, 6, etc. Project the points 4, 5, 6, etc. downwards to intersect the arc $J E''$ in the elevation, thus fixing the points $4'$, $5'$, 6, etc. From the latter points draw horizontal lines, as shown, and from the points $1'$, $2'$, $3'$, etc., on the line $A'\ B'$ in the plan, draw vertical lines downwards to intersect the horizontal lines in points 1, 2, 3, etc. Other points between 3 and A may be found in the same way. Then a smooth curve drawn through A, 1, 2, and 3 will be one-half of the required curve. The other half is exactly like the one just drawn, and may be obtained in a similar manner.

64. Development of Surface of Section of Cone. Fig. **11** shows a cone 3 inches high, 2 inches in diameter at the base, and cut by a plane. Fig. **12** shows the development.

The elevation and the projection of the base of the cone are drawn as shown in Fig. **11.** First locate a horizontal center line $1\frac{5}{8}$ inches from the lower border line, and on it, at a distance of 8 inches from the left-hand border line, draw a vertical line for the base of the cone, which is 2 inches in diameter. From this base line, measure to the left on the center line a distance of 3 inches, the height of the cone, thus locating the point O, from which draw the inclined sides of the cone to intersect the base. The cone is cut off at an angle of 50° with the base line. The projection of the base is now drawn in order to determine the position of the elements on the conical surface.

The plan is represented by the dotted circle and is divided into a convenient number of equal parts, in this case twelve. These points of division, 1, 2, 3, etc., are projected to the base line of the elevation in points $1'$, $2'$, $3'$, $4'$, etc., and projection lines are drawn from points $1'$, $2'$, $3'$, etc. to the point O in the

elevation to represent the elements on the surface of the cone. These elements intersect the cutting plane in points A, B, C, etc. Now begin the development in Fig. **12** by locating point O' $3\frac{3}{8}$ inches from the right border line and $3\frac{13}{16}$ inches from the lower border line. With the pencil compasses set to a radius equal to the slant height of the cone, as *O 1′* or *O 7′*, in Fig. **11**, describe an arc *1–1′*. Make the length of this arc equal to the length of the circumference of the circular base of the cone. This

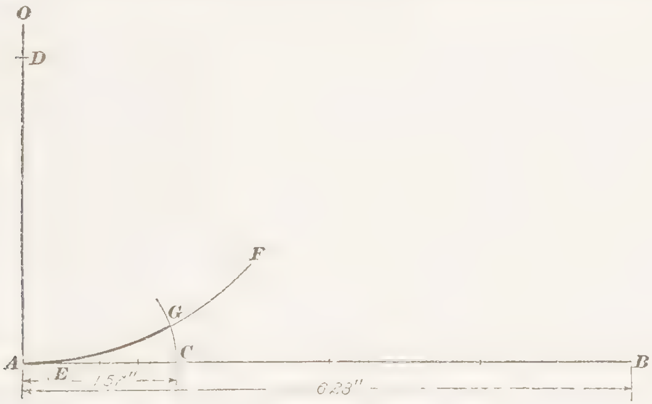


Fig. 62

may be conveniently found as follows: The length of the arc will be $2 \times 3.1416 = 6.28$ inches, nearly. To lay off an arc of this length, the following method may be used:

65. On a separate piece of paper, in the manner shown in Fig. 62, draw a horizontal line *A B*, 6.28 inches long, equal to the circumference of the base of the cone shown in Fig. **11**, and erect a perpendicular *A O*. Divide the line *A B* into four equal parts, each of the divisions to measure $6.28 \div 4 = 1.57$ inches. Also divide one of these parts, as *A C*, into, say, four equal parts.

With the pencil compasses set to a radius of *O 1′*, representing the slant height of the cone in the elevation in Fig. **11**, describe a short arc from the point *A*, cutting the vertical line *A O* in *D*. With the compasses set to the same radius and with *D* as a center, describe an arc tangent to the horizontal line *A B*. Then, with *E* as a center and *E C* as a radius,

describe an arc cutting the arc $A F$ in G; then the arc $A G$ is equal in length to the line $A C$, and $A C$ is one-fourth the length of the required arc. (Note that, for convenience in this case, Fig. 62 has been reduced to a different scale than that of Fig. **12**, which is the reason that measurements in the two do not correspond.)

66. Next, with the dividers set to the chord of the arc $A G$ found in the manner just described, begin at point *1* and space off on the arc in Fig. **12** this chord distance four times, marking the points of division between the spaces, as *4*, *7*, *10*, and determining the point $1'$; then the arc 1–$1'$ will measure 6.28 inches. Each of the four divisions should now be subdivided into three equal parts so that the entire arc is divided into twelve equal parts, as *1*, *2*, *3*, *4*, etc. Join the points of division *1*, *2*, *3*, etc. with the center O' by the lines $O'\,1$, $O'\,2$, $O'\,3$, etc., as shown. On the radial lines $O'1$, $O'2$, $O'3$, etc., of Fig. **12**, the points that will determine the exact shape of the curve will now be located.

In Fig. **11**, A, B, C, D, etc. are points of intersection between the radial elements $O\,1'$, $O\,2'$, $O\,3'$, etc. of the cone and the cutting plane, as shown. Only the two outside elements $O\,1'$ and $O\,7'$ can be measured directly from this view. The other elements are inclined from the observer, and so do not appear in their true lengths. The line $O\,D$, for example, if measured on the surface of the actual cone, would evidently be of the same length as the line $O\,D'$; but in the elevation it is much shorter. Therefore, all points, as B, C, D, etc., must be projected parallel to the base line of the elevation of the cone to intersect the inclined outside element $O\,1'$ in points B_1, C_1, D_1, etc.

Now continue drawing Fig. **12** by setting off distances $O'A$, $O'B$, $O'C$, etc., equal to the distances OA, OB_1, OC_1, etc., taken from Fig. **11**, and through these points draw a curve, which will be the desired development of the intersection.

A plate cut of the same size and shape as shown by A–G–A'–$1'$–7–1 can be bent into the conical surface shown in the elevation A–G–$7'$–$1'$.

Particular attention must be given to the method explained above for transferring certain points from the elevation to the

development in Fig. 12. As previously stated, it would be wrong to take measurements from lines *O F*, *O E*, *O D*, etc., as these lines are not represented in their true length until projected to the inclined line *O 1′*, from which the distances are transferred to the development in Fig. 12.

The pattern in Fig. 12 may be laid off, also, by making the radial divisions on the arc *1-1′* equal to the circumference of the cone in Fig. 11 by dividing the distance, which is laid off on a straight line, into as many equal parts as desired. The greater the number of parts into which the line is divided, the nearer these distances approximate a straight line when they are transferred to the arc in Fig. 12.

SHADE LINES

67. The purpose of shade lines on drawings is to show at a glance, without reference to any other view, whether parts represented project above the plane of the surface of the object or whether they are depressions or holes. The value of shade

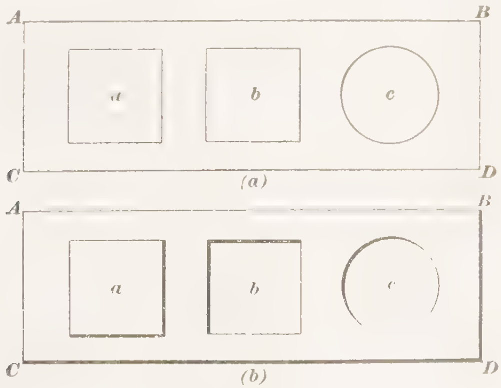


FIG. 63

lines may be seen by comparing the two illustrations shown in Fig. 63 (*a*) and (*b*). In (*a*) the object is rendered with an outline of uniform thickness, and it is not evident whether the shapes of the parts *a*, *b*, and *c* are raised parts or holes. In (*b*)

is shown a drawing of the same object properly shade-lined, which indicates that a is a projecting boss and that b and c represent holes. To determine the height of the bosses, the thickness of the plate $A B D C$, and the depth of the holes, another view would be necessary.

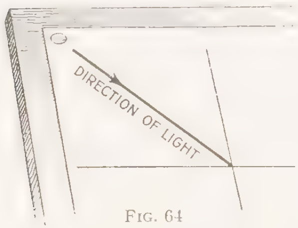


Fig. 64

68. Principles Governing the Location of Shade Lines.—In order that the system of shading may be uniform on all drawings and thus have the same meaning to all, the light is assumed to come in one invariable direction. The light rays are considered as being parallel to the plane of the paper, to make an angle of 45° with all horizontal and vertical lines of the drawing, and to come from the upper left-hand corner of the drawing, as shown in Fig. 64.

A view may be placed in any position on the drawing, but the source of light is always stationary; hence, the lines to be shaded depend on the position of the view. Each view is shade-lined independent of any other. The same principle applies whether the view is a plan or an elevation.

If the rays of light are represented by parallel lines drawn at an angle of 45° with the vertical and horizontal lines, any edge of an object that is touched by such lines is called a light surface; an edge that cannot be touched by lines having this angle is called a dark surface and is represented by a shade line, which is made heavier than the other lines.

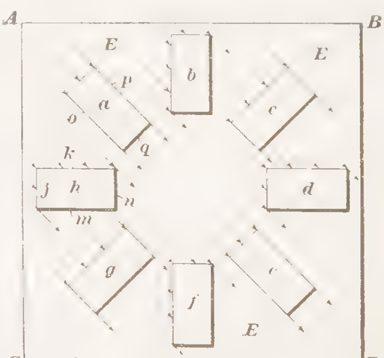


Fig. 65

Fig. 65 shows a square plate $A B D C$, from the surface of which eight rectangular blocks project. The blocks radiate from a center. This example is given to show which edges of the

rectangles should be shade-lined when the rectangles are in different positions. The light is at an angle of 45° and parallel to the plane of the paper, and therefore all surfaces of the object that are parallel to the plane of the paper will be light, such as the surfaces *E* and *a*, *b*, *c*, etc. The light rays, indicated by the arrows, strike certain edges of the projecting rectangles which represent surfaces that are perpendicular to the planes *a*, *b*, *c*, *d*, *e*, *f*, etc.; the edges touched by these light rays therefore remain light edge lines, and the remaining edges of the rectangles are hidden from the light and are shade-lined.

To illustrate more clearly the idea, at *h* the light rays touch the edges *j* and *k*; and edges *m* and *n* are shade-lined, because these edges are not illuminated. When an object is in the position as at *a*, the two sides *o* and *p* are parallel to the light rays and remain as light lines, and the only edge shade-lined is *q*. Sometimes for the sake of appearance the edge *o* is shade-lined; for example, an arm of a pulley may come parallel to the light rays and in this case the draftsman would use his judgment.

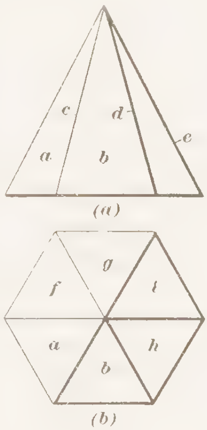


FIG. 66

69. When objects have surfaces that are inclined to the plane of the paper, the edge lines formed by the intersection of these surfaces are shade-lined according to certain rules. For example, in Fig. 66 is shown an elevation and a plan of a hexagonal pyramid.

In the elevation (*a*) the light rays touch the surfaces *a* and *b*, consequently the edge line *c* formed by the intersection of these two planes will be a light line, by the application of the rule that, *Any edge that is formed by the intersection of two light surfaces will be a fine line.* At *d* the edge is shown shade-lined according to an application of another rule that, *All of the edges formed by the intersection of a light and a dark surface are shade-lined.* The edge line *e* is also a shade line, as it is an intersection of two dark surfaces.

In Fig. 66 (*b*) is shown a plan view of the hexagonal pyramid, and this view is shaded without regard to the elevation, it being considered as an independent object and shade-lined accordingly. The surfaces *a*, *f*, *g* are illuminated by the light rays, and the intersection of the light surfaces *a*, *f*, and *g* are light edge lines. The edges between *g* and *i* and *a* and *b* are the intersections of light and dark surfaces and require shade lines. The surfaces *i*, *h*, and *b* are dark surfaces and the intersections between them are shade-lined.

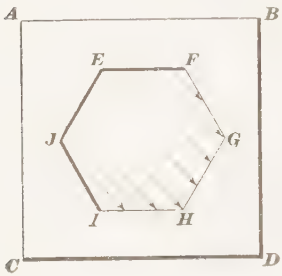


Fig. 67

70. In shading holes or depressions, a slightly different assumption is made in the direction of the light. If the light, in the example shown in Fig. 67, passed over the surface of *A B D C* parallel to the plane of the paper, as previously assumed, all of the inside surfaces would be dark and the entire outline *E F G H I J* would be shaded. In order to prevent this and to make the work appear similar to that which has preceded, the rays of light are assumed to make an angle of 45° with the plane of the paper. In Fig. 68 is shown an illustration of how the light rays are assumed to strike the edges of all holes and depressions. Hence, in Fig. 67 the light will strike the surfaces whose edges are *F G*, *G H*, and *H I* as shown by the arrows, leaving the surfaces whose edges are *E F*, *E J*, and *J I* dark as before. Therefore, these latter edges will be shaded, and the edges *F G*, *G H*, and *H I* will be light.

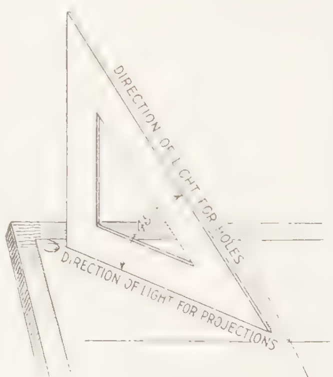


Fig. 68

71. In Fig. 69 is shown the method by which shade lines are added to two concentric circles to convey the idea of a raised surface and also of a circular hole.

After inking the outer or large circle with the pen compasses, draw a pencil line *a b* through its center at an angle of 45°, which is the angle at which the light rays are assumed to illuminate the edges. At right angles to this line and through the center *x* of the circle draw another pencil line. With the compasses set to the same radius, shift the instrument to the point *y* and draw a semicircle that will blend into the outline at the points *c* and *d*. The light rays illuminate the edge *c i d*, which is one-half of the circle, and the remainder is in shade. The inner circle is now inked in, and the compasses, kept to the same radius, are shifted to center at the point *y*, and from this point another semicircle is drawn which will form a shade line at *e f g*; the edge *e h g* will be a fine line, as that part of the circle is illuminated by the light rays.

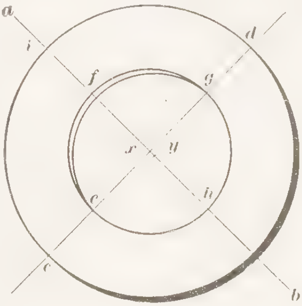


FIG. 69

There are now two crescent-shaped spaces which are to be filled in with a lettering pen to bring out the effect of the shade line. The shade line of the larger circle is shown filled in.

The thickness of the shade lines is left to the draftsman's judgment. The compasses can be shifted along the line *a b* to any desired distance, but the thickness of these shade lines should correspond with those on other parts of the drawing. When shifting the compasses to a new center, care must be taken to do this accurately on the line, otherwise the semicircles will not be tangent at the desired points.

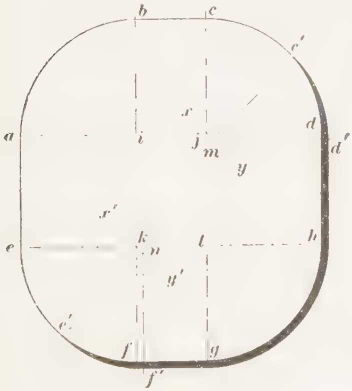


FIG. 70

72. In Fig. 70 is shown the method of shade-lining an object having rounded corners connected by straight lines at right angles to each other.

The arcs *a b*, *c d*, *e f*, and *g h* are inked first, care being taken that the arcs do not extend beyond the points of tangency, and the straight lines are then drawn to meet them. The centers from which these arcs are described are indicated at *i*, *j*, *k*, and *l*. The main purpose of the illustration is to show how the center point is shifted to describe the required shade lines to conform to the principles of light and shade as already given. The arc *a b* and the straight lines *a e* and *b c* are light edges, but arcs *c d* and *e f* are partly shade-lined.

To add the shade lines on the arcs *c d* and *e f*, the compasses are set to the radius of the arc, and the centers are shifted from *j* and *k* along the 45° lines *x y* and *x′ y′* to the points *m* and *n*, respectively, and arcs are drawn tangent to arcs *c d* and *e f*, from the points *c′* and *e′* to *d′* and *f′*.

The arc *g h* is shade-lined without changing the center, by adjusting the pen to the desired thickness of shade line. The shade lines on the straight edges are then added.

Experienced draftsmen save time by shade-lining at the same time the work is being outlined.

Shade lines are extensively used on mechanical drawings in technical publications, as the details can be made clearer and fewer views of the subject are necessary. Shade lines are required on patent-office drawings.

MECHANICAL DRAWING
(PART 1)

INTRODUCTION

DRAWINGS AND DRAWING PRACTICE

1. While every drawing executed by means of the T square, triangles, and other drawing instruments, is a mechanical drawing, this term is usually restricted to drawings representing machines, machine parts, and objects used in the mechanic arts. A **mechanical drawing** is the means whereby a machine or mechanical device is graphically shown by outlines, sections, and projections.

The object of the mechanical drawing may be to present the inventor's idea for patent purposes, to convey to the prospective purchaser the appearance and dimensions of a machine or part, or, more commonly, to transmit the designer's idea to the mechanic who constructs and assembles the different parts to a complete whole.

The mechanical drawings serve another important purpose; that of giving a definite and visible form to the designer's idea in order to assure him that the different parts will properly fit together and perform their intended functions.

WORKING DRAWINGS

2. A mechanic constructing a machine or machine part from drawings requires not only a true representation of the object to be made, but all its dimensions as well. The drawing

must also give other instructions, such as the material to be used, the method of manufacture, etc. A mechanical drawing of this kind is called a **working drawing.**

Working drawings are divided into two general classes; namely, *assembly*, or *general, drawings* and *detail drawings.*

Assembly, or general, drawings give the workman the relation between, and the places or positions occupied by, the component parts of a structure, machine, device, fixture, implement, etc. If any dimensions are given they are the principal ones, such as distances between the center lines of the main parts of a machine or engine, etc.

Detail drawings show the exact shape and size of each individual part and also the material. For this purpose they are supplied with all the dimensions required by the workman and any explanatory notes that the draftsman may consider necessary.

Detail drawings may be made so complete that they will answer for the patternmaker, blacksmith, and machinist, and they are usually so made in the smaller shops. In the large shops, however, separate drawings are often made for these men; the detail drawing for the use of the patternmaker then contains only the dimensions and notes needed by him to make the pattern; that for the blacksmith contains only the dimensions needed for making the forging; and, finally, that for the machinist contains only the dimensions needed by him.

Attention is called to the fact that practice varies in regard to the dimensions given on detail drawings, at least so far as drawings for the patternmaker and blacksmith are concerned. In some places, the dimensions given represent the size the object is to be when finished; hence, the blacksmith or patternmaker must make the necessary finishing allowances himself. In other places the finishing allowance is made by the draftsman; the dimensions given are then those of the pattern or forging. If in doubt about the practice followed in a particular drawing office, inquiry should be made as to what system is used.

In the drawings which follow, the finished dimensions only are given, the necessary allowances being made by the patternmaker or blacksmith.

3. While the systems used in the drawing offices of the leading manufacturing companies for producing drawings vary in many important details, good drawings made in one office can be read in others, and the parts represented can be made in other shops, even when the office and shop practices differ to a marked degree. In general, all mechanical drawings are made as plain as possible, shading and other aids to the eye being omitted except on complicated drawings, when shade lines are occasionally used in order to bring out the important features of the design. The shading of surfaces, lines, and holes is not customary on working drawings, but when used, the methods given in *Geometrical Drawing* will be followed.

It is not good practice to spend time on elaborate titles or figures. Plain letters, easily read, serve all purposes and do not waste the time of the draftsman.

The methods here described are those that have been found to be the most representative and complete, and the draftsman can easily adapt himself to any local regulation, if the principles here explained do not agree in every particular with the practice in the office in which he is employed.

DUTIES OF DRAFTSMEN

4. A brief description of the duties of the draftsman, according to his rank and experience in the modern drafting room, is given herewith. There are usually three, and sometimes four, grades of men:

1. The *designing engineer*, or *designer*, who, as his name indicates, designs the apparatus.

2. The *leading*, or *chief*, *draftsman*, who takes the ideas of the designer and works them up into practical form. Very often the designer does his own laying-out work, and, in such case, fills both the position of chief draftsman and designer.

3. The *detail*, or *junior*, *draftsman*, who works either directly or indirectly for the leading draftsman, takes the assembly drawings or sketches and works out the details calling for proper material, parts, and quantities. His work approaches more nearly to that of the leading draftsman as he gains in skill.

4. The *tracer*, who takes the pencil detail drawings, and makes tracings for reproduction; his work in turn approaches that of the detail draftsman as he gains in skill and experience. As a rule, the beginner without previous practical experience will start work as a tracer. If he does this work neatly and intelligently, and devotes his spare time to technical studies, he can count upon promotion to the more responsible position of detail draftsman, if opportunity offers, from which position he can then advance himself higher and higher.

The distribution of duties outlined above would meet the requirements of the average, medium-sized establishments. These requirements vary considerably from the small shop employing a single draftsman up to the large concerns with their corps of consulting and designing engineers and hundreds of draftsmen and tracers.

ACCURACY AND NEATNESS IN TRACING

5. Tracings are usually required quickly, but this does not mean that the work may be inaccurate or carelessly done. A systematic method will greatly facilitate the work and give better results. The tracer must study the pencil drawing to be traced to familiarize himself with the shapes of the various parts, and he will thereby save much erasing.

The necessity of carefully following all instructions in making tracings cannot be too forcibly presented. Slovenly work will at once create a bad impression, while painstaking work, and carefully made and presentable tracings, will immediately place the tracer in favorable standing with his employers. At the start it is better to work slowly until the subject presented is well in hand and perfectly understood. While speed is important, accuracy must come first.

The drawing office routine generally provides for checking of the work—design and details—as well as the tracings. This is, however, the employer's safeguard; and the draftsman's responsibility is not lessened by the practice of having the drawings checked.

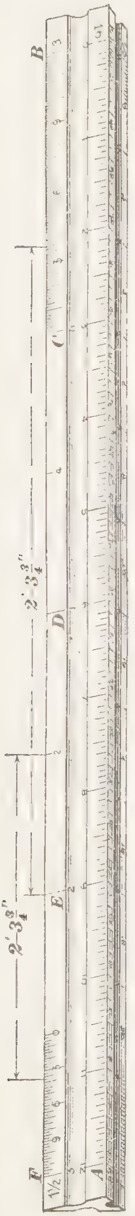


FIG. 1

SCALES OF DRAWINGS

6. It is seldom convenient to make full-size drawings of mechanical devices that are to be manufactured; and even if such drawings could be made, there would be so many different sizes that it would be inconvenient to file them away systematically. For these and other reasons the usual practice is to make drawings to a reduced scale, proportionate to the full size. Thus, if a piece of work is large, a drawing of a convenient size may be obtained by making all the dimensions either one-half of the actual size, or one-fourth, or one-eighth, as the case may be. A drawing of a very small mechanism, however, is made to a larger scale than the object itself. If a drawing is to be made one-half size, it is drawn to a scale of 6 inches to a foot and marked, *Scale 6 inches = 1 foot*, or sometimes it is marked, *Scale* $\frac{1}{2}$ *size*. This use of a fraction to express the fact that the drawing is made one-half the size of the object should not be confused with the case where a drawing is to be made to a scale of $\frac{1}{2}$ inch = 1 foot, as the latter scale represents $\frac{1}{24}$ of the full size. Every half inch on the scale of 6 inches to a foot corresponds to 1 inch on the object; that is, every dimension is only one-half of the real length. For example, to lay off a line $5\frac{7}{8}$ inches long to a scale of 6 inches = 1 foot, measure off 5 half inches and 7 sixteenths, on the full-size scale; a line of this length is a $5\frac{7}{8}$-inch line drawn to a scale of 6 inches = 1 foot.

7. In Fig. 1 is shown an instrument called a **scale**, that is used for laying off or measuring distances on mechanical drawings. It is triangular in form and its edges contain eleven

different systems of subdivision, which are sufficient for all work ordinarily done in a drafting room. The scale is over 12 inches long and is graduated for a distance of 12 inches. The lower edge *A*, as shown, is the full-size scale, and it is divided into inches and fractions of an inch down to sixteenths; it is used for drawings in which an object is represented to actual size, and for taking dimensions from the object itself.

On the opposite edge, at *B*, is shown the quarter-size scale, 3 inches to the foot. The distance *B* to *C* is actually 3 inches on the scale, but it represents 1 foot on an object that is to be drawn to a quarter-size scale. The distance *BC* is subdivided into 12 parts representing inches, and each of these is divided into proportional parts representing $\frac{1}{2}$-, $\frac{1}{4}$-, and $\frac{1}{8}$-inch divisions. From *C* to *D*, *D* to *E*, and *E* to *F*, the scale is marked in its main divisions of 1 foot each, each division being 3 inches long, actual size.

It will be observed that the numbering of the feet divisions on these scales does not begin at the end of the instrument, but at the first main division from the end. Thus, on the scale of 3 inches = 1 foot, the zero mark is placed at *C*, and the first foot is measured to *D*. This is done so that the feet and inches may be laid off with one reading of the scale. On this scale the figures indicating the number of feet are placed along the edge of the depression, as indicated at *D*, *E*, and *F*. The numbers representing inch divisions are numbered in the opposite direction to those representing feet, and always begin at a zero mark and read toward the end of the scale. To lay off 2 feet $3\frac{3}{4}$ inches, to a scale of 3 inches = 1 foot, place the scale so that the 2-foot mark, as at *E*, will be at one given point and lay off $3\frac{3}{4}$ inches beyond the zero mark *C*; then the distance between this point and *E* will represent 2 feet $3\frac{3}{4}$ inches.

On the other end of the scale, but on the same edge, this same distance is shown laid off, in a similar manner, to a scale of $1\frac{1}{2}$ inches = 1 foot. The figures in this case read in the opposite direction to the others, and those indicating feet are placed nearer the edge to prevent confusion with the zero mark and the inch divisions of the 3-inches-to-the-foot scale. These various scales would be marked on the drawing: Scale 3″ = 1 ft., $1\frac{1}{2}$″ = 1 ft., etc.

The other edges of the instrument are divided into scales of 1 inch and $\frac{1}{2}$ inch, $\frac{3}{4}$ inch and $\frac{3}{8}$ inch, $\frac{1}{4}$ inch and $\frac{1}{8}$ inch, and $\frac{3}{16}$ inch and $\frac{3}{32}$ inch to the foot. The practice of different makers varies in regard to the scales that are arranged together along the same edge, but the methods of division are the same. The dimensions given on a drawing are always followed, but it is also customary to state on a drawing the scale to which it is made. This is particularly necessary on detail sheets where parts have been drawn to different scales, the more complicated parts being drawn as near full size as possible, and the less complicated parts being drawn to a much reduced scale.

8. When the size of his sheet is limited and a general drawing of some object is desired, the draftsman may be obliged to make a special scale. In such a case, one scale may be too large

Fig. 2

to enable the drawing to be made on a sheet of the required size; another scale may make it too small to show up well. For example, a $\frac{1}{8}$ scale may be too large and a $\frac{1}{16}$ scale too small; a $\frac{1}{12}$ scale may be just right. If the draftsman has no $\frac{1}{12}$ scale (that is, a scale of 1 inch to the foot), he may make one by taking a piece of heavy drawing paper and cutting out a strip about the size of an ordinary scale and laying off the inch divisions on it. Each division or part will then represent 1 foot on the object. Divide one of the end parts into 12 equal parts and each will represent 1 inch on the object. Lines indicating half and quarter inches may be drawn if considered necessary.

Fig. 2 shows part of a scale made in this manner, giving feet, inches, and half-inches—the quarters, eighths, etc. of an inch being judged by the eye.

To make a $\frac{1}{5}$ scale, lay off 12 inches and divide this distance into 5 equal parts, using one of the methods described in *Geometrical Drawing*. Using the same method, divide one of the end divisions into 12 equal parts, to represent inches, and then divide each of these parts into halves, quarters, eighths, etc.

DRAWING PLATES

GENERAL INSTRUCTIONS

9. The general instructions which follow apply to all the mechanical-drawing plates treated in this Section.

From the start, it should be remembered that it is essential to do neat and accurate work; that all lines, figures, and letters must be clear-cut and distinct; that there must be no doubt as to the meaning of limits or dimensions; that mistakes made on drawings are often more serious than errors in the shop, for they may not be located until the various parts of the machine are to be assembled. The draftsman must also keep in mind the necessity of making drawings concise, but not needlessly complicated; that dimensions are not to be duplicated; that when working drawings once leave his hands as complete it should not be necessary to refer to him for further particulars.

10. Size of Plates.—The plates are to be of the same size as those drawn in connection with *Geometrical Drawing*, 14 in.×18 in., with border lines drawn $\frac{1}{2}$ inch from edge, making the working limits of the drawing 13 in.×17 in.

11. Title and Number of Drawing.—The title or name of the drawing is to be placed in the lower right-hand corner of sheet, and a space of $1\frac{1}{2}$ in.×4 in. is to be reserved for this title; the height will vary, but the length will always be 4 inches. In addition to the title, there will be given in this space the number of the drawing, the draftsman's name, and the date when the drawing was finished. If desired, the date can also be given when the drawing was begun.

12. Fractions.—Fractions are to be written with dividing line horizontal, thus: $\frac{3}{4}''$, $\frac{7}{16}''$; never thus: 5/16″, with dividing line inclined.

13. Abbreviations.—Abbreviations are used on drawings only when lack of space prevents use of the complete word, although there are a few abbreviations that can be used without hesitation, having been practically fixed by long practice, thus: D. or "Diam." for diameter; R. or "Rad." for radius; "Thds." for threads; f. for finish.

14. Definitions.—The word **drill** placed near a dimension or hole is always taken to mean that a hole is put through the object by drilling.

Ream or **reamed** placed near a hole means that the hole is finished by reaming.

The word **tap** following a dimension and a number always means that the hole is to be finished by tapping with a tap of the dimensions given; that is, "$\frac{1}{2}$–13 tap" would mean that the hole is to be tapped with a $\frac{1}{2}$-inch tap, 13 threads to the inch.

The word **cored** implies that finish is unnecessary, the hole being produced by a core, which is placed in the mold when the casting is made. Cores are arranged for by the patternmaker.

The terms **shrinking fit, driving fit, forced fit,** and **turning fit,** always imply that the workman is to make allowance for the kind of fit called for. The holes are usually made to nominal dimensions, and the necessary allowance made on the part which goes into the hole.

"f" all over means that the part is to be finished all over.

When wishing to convey special information, write your note in plain English so that it cannot be misunderstood.

15. Dimensions.—All dimensions above 24 inches are to be given in feet and inches, the inches being designated by accent (″) mark, and feet by abbreviation ft., thus 6 ft. $4\frac{1}{2}''$; never use accent mark for feet, as there is then danger of confusion.

When micrometer or gauge measurements are required, all dimensions are given to three decimal places; thus, 1.000″ would indicate 1 inch measured with gauge or micrometer;

6.250″ would indicate $6\frac{1}{4}$ inches, and 0.250″ would indicate $\frac{1}{4}$ inch, all measured in the same way. Note that a zero should always be placed ahead of the decimal point when the dimension is less than 1 inch; this avoids all confusion as to the value of the decimal.

Where possible, all dimensions should be placed so that they can be easily read when the drawing is viewed from either the bottom or from the right-hand side.

Dimensions always start from some finished surface, or center line, this giving a base from which work can be checked.

16. Pencil Drawings and Tracings.—In modern shop practice, pencil drawings are not sent to the shop for reference; but for this purpose reproductions are made from them in the form of blueprints.

Ink tracings are made from the pencil drawings on a semi-transparent tracing cloth from which the blueprints are made by a process that will be described later on. It is not necessary to ink the pencil drawing, although it may be retained as a record.

Following the usual shop practice, the drawings made in connection with the study of this subject will first be made in pencil and afterwards traced. The methods to be followed in making the pencil drawings will be those that have been used in penciling the plates in *Geometrical Drawing*. For the pencil drawing a good grade of manila paper upon which lines can be easily drawn and erased is sufficient. The tracing cloth is then placed over the paper drawing and the lines are inked in on the cloth. All ink lines on tracings must be uniformly black without regard to the width of these lines.

At first it will be found somewhat difficult to get lines that are distinct and uniformly black, but by strictly following directions, it will become quite as easy to make a good tracing as it is to ink in the drawing on drawing paper.

The plates to be drawn in connection with this subject are numbered, beginning with 1001. They are to be drawn in the order of their numbers.

CONVENTIONAL METHODS

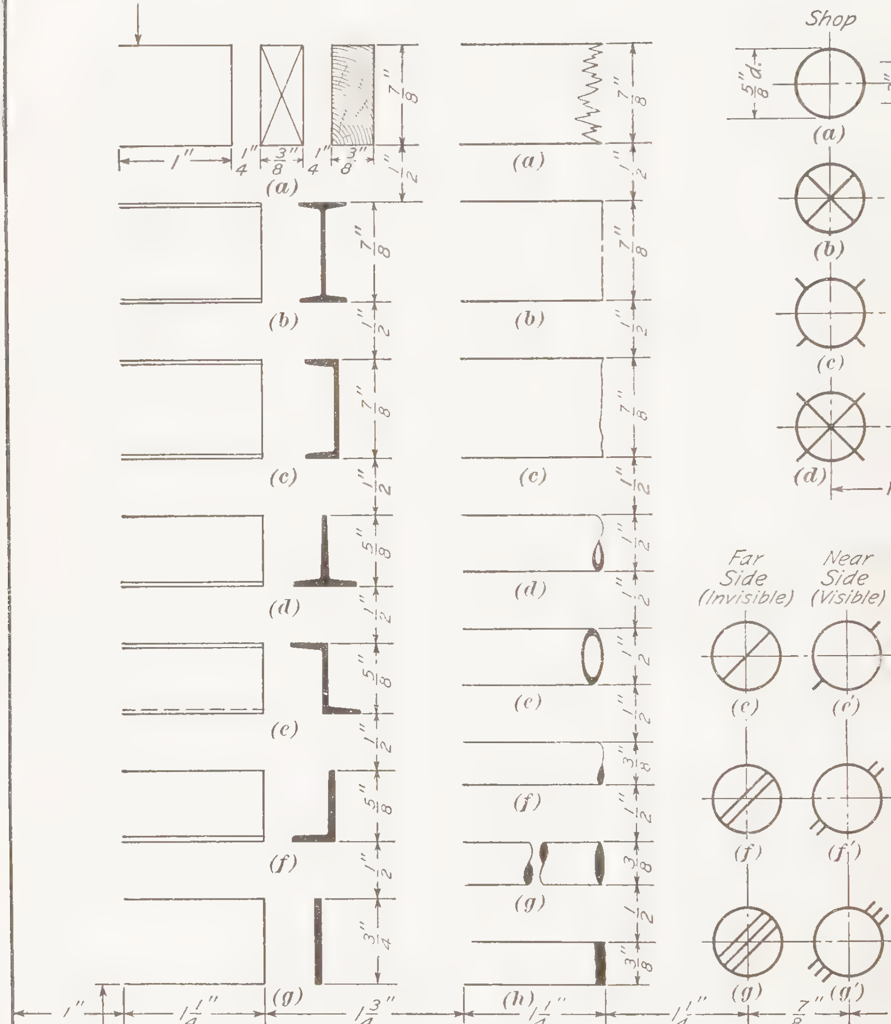


Fig. 1 Fig. 2 Fig. 3

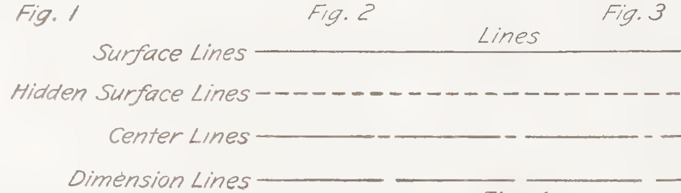


Fig. 4

DATE

39B-I.L.T. 54C-154. 8 14

EPRESENTING MATERIALS

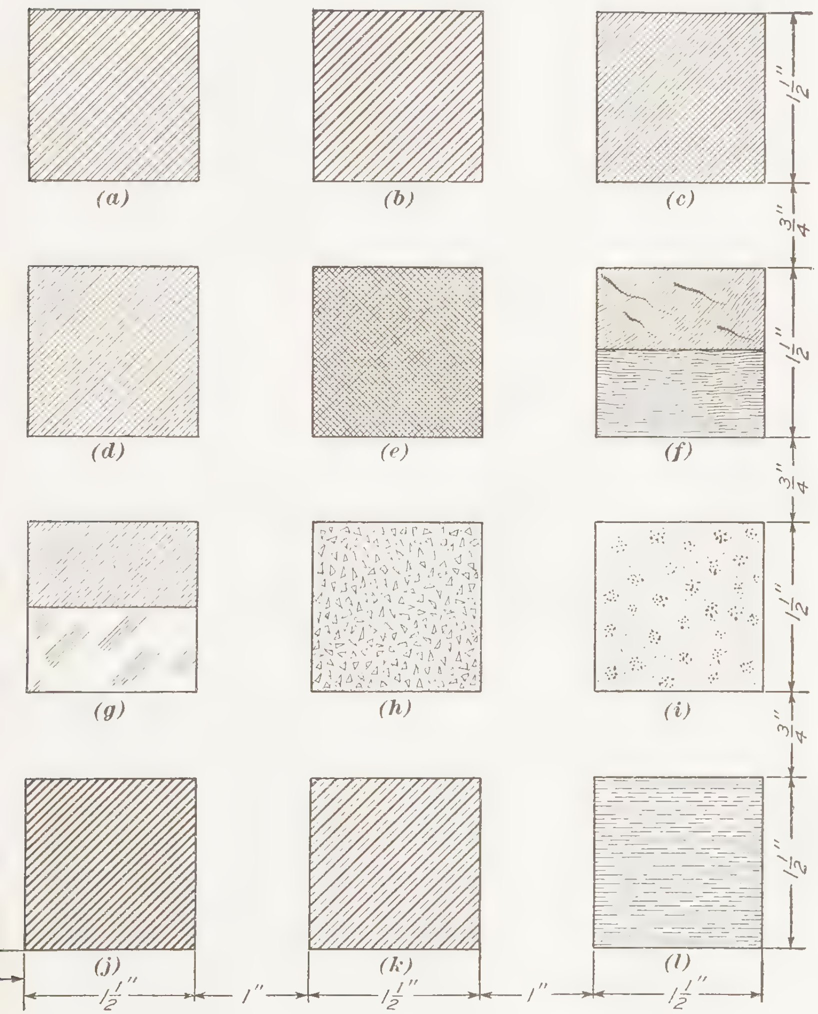


Fig. 5

$4''$

$1\frac{1}{2}''$

DRAWING ROOM SYMBOLS

DRAWN BY................

DATE ....

1001

PLATE 1001, TITLE: DRAWING-ROOM SYMBOLS

17. Plate 1001 is intended for a practice sheet in tracing, and at the same time to serve as an introduction to the regular routine of drawing-room work. The conventional methods of representing materials which are shown in this plate have been adopted for general use by all the leading drawing rooms and engineering offices.

In order to distinguish readily between them, references to figure numbers on the drawing plates will be printed in heavy-faced type and those in the text in ordinary type.

EXPLANATIONS OF THE FIGURES

18. Shapes.—The five figures on this plate are, strictly speaking, five groups of figures. Thus, Fig. **1** shows in part (*a*) the side, and two methods of representing the end of a wooden beam, and parts (*b*), (*c*), (*d*), (*e*), (*f*), and (*g*) show simple rolled iron or steel forms, called *shapes*, which are commonly used in the frames of modern iron and steel structures. Part (*b*) represents the side and the section of an **I** *beam;* (*c*) a *channel bar*, or *channel;* (*d*) a **T** *bar;* (*e*) a **Z** *bar;* (*f*) an *angle bar*, or *angle;* and (*g*) a *flat bar*, or *flat*.

19. Breaks.—Fig. **2** shows the conventional practice of indicating *breaks*. When a long and comparatively slender object is to be drawn, it often happens that, when laid out to a sufficiently large scale to make it clear, it will extend beyond the available space. In that case the view of part of the object is broken away and omitted and the other parts are brought closer together, care being taken to let the place of the break be at such a point that the remaining part will indicate the transverse dimensions and shape of the part removed. An object is also frequently shown broken off when it is unnecessary to show it complete. The fact that part of an object is broken away in the drawing is indicated by a so-called **break**.

In Fig. **2** are shown some common ways of indicating breaks in different objects and materials, and it will be noticed that

usually they show an outline that indicates the shape of the object.

Wood is usually shown broken in the manner indicated in view (*a*). Views (*b*) and (*c*) show two ways of indicating a break in a metal plate or beam; that in (*c*) is the more common method, though the dot-and-dash line shown in (*b*) is often used. Pipes and similar cylindrical objects are generally shown broken as in (*d*), but the method shown in (*e*) is also used. A break at one end of a round rod is shown in (*f*), and a break in a similar rod where part of the rod between the two extremities

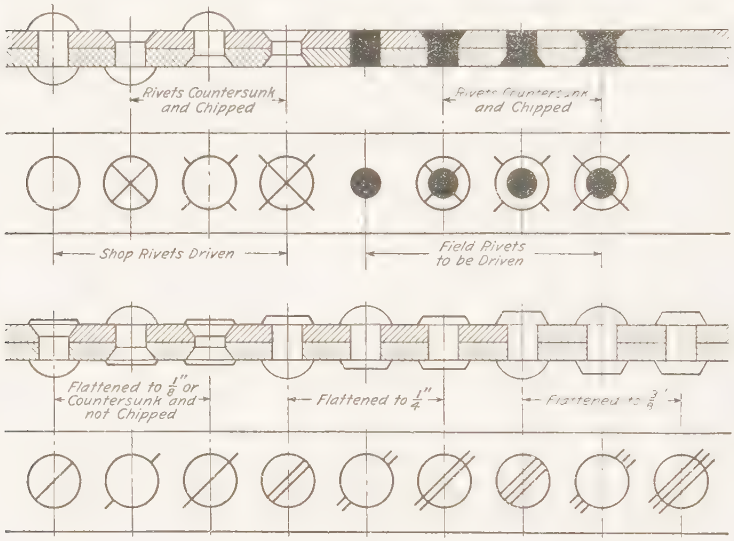


FIG. 3

is omitted is shown in (*g*). Breaks in rectangular objects are often shown as in (*h*). As a rule, breaks are indicated by section lines, but in small objects or in views drawn to a small scale it is sufficient to show the break in black.

20. Structural Rivets.—In Fig. **3** is shown Osborne's code of conventional signs for structural rivets, as used by many of the leading structural-steel companies. The sectional views in Fig. 3 will help to make clear the meaning of the different signs and the terms *round*, *flattened*, *countersunk*, and *chipped*

heads. Rivets that are driven in the shop are called **shop rivets,** and those left to be driven during the erection of the structure, or "in the field," are called **field rivets.**

The basis of this system of signs consists of an open circle to represent a shop rivet, a blackened circle to represent a field rivet, a diagonal cross to represent a countersunk head, and a 45° diagonal stroke or strokes to represent flattened heads. The diagonal cross indicates not only that the rivet head is to be countersunk, but also that it is to be chipped off even with the surrounding material. If the rivet is to be countersunk, but not chipped, the sign indicating to flatten to $\frac{1}{8}$ inch may be used. The positions of the diagonal lines with reference to the circle (inside, outside, or both) indicate whether the rivet head is countersunk into the far side (invisible), the near side (visible), or both sides of the material. Similarly, the number and position of the diagonal strokes indicate the height and position of the flattened head. Any combination of shop or field rivets, with round, countersunk, or flattened heads, can be readily indicated by the proper combination of these signs.

The cross-section in Fig. 3 shows the forms and positions of shop-rivet heads, and the marks by which they are indicated. In the part referring to field rivets, the positions and shapes that are to be made in the field are shown for all except the first one, which, according to the indicating marks, is to have a full head on each end. It is well to remember that any indicating mark, whether cross or diagonal, if confined *within* the circle, shows the form and finish of the far, or invisible, head of the rivet; if the diagonals are *outside* the circle *but do not cross it*, they refer to the near, or visible head; if they extend *across and outside* the circle, they refer to both heads of the rivet.

In Fig. **3**, (*a*) and (*a*′) indicate two full heads, (*b*) and (*b*′) indicate rivets countersunk on the far side (invisible) and chipped; (*c*) and (*c*′), rivets countersunk on the near side (visible) and chipped; (*d*) and (*d*′), rivets countersunk on both sides and chipped; (*e*) (*e*′) and (*e*″) indicate rivets flattened to $\frac{1}{8}$ inch high or countersunk and not chipped; (*f*) (*f*′) and (*f*″), rivets flattened to $\frac{1}{4}$-inch high, and (*g*) (*g*′) and (*g*″), rivets flattened to $\frac{3}{8}$-inch high.

21. Lines.—Fig. 4 shows the different kinds of lines used on the drawing plates accompanying these Instruction Papers on Mechanical Drawing.

The style of lines indicated for **surface lines** is used on drawings to represent the limits or outlines of visible surfaces.

The outlines of **hidden surfaces,** that is, those hidden from view by other intervening surfaces or parts, are represented by dotted lines as shown. It will be noticed that parts hidden, and therefore dotted, in one view, are sometimes drawn with full lines in other views; this indicates that from one position the dotted part cannot be seen, while in the other it can.

Center lines of the style used in Fig. 4 are usually placed on the drawing at the working center of the object shown, and are extremely important, as they indicate the point from which work is to be laid out. Dimensions are frequently given from the center lines and they serve as a guide for all dimensions. In making a working drawing it is important that one of the center lines should be first located, as this will immediately fix the starting point of drawing. This working point is not necessarily the geometrical center of the figure, but is fixed by some important point about which the delineation begins and which is relatively important in the complete object.

The same style of line as is used for center lines is also used to indicate where a section has been or is to be taken. If, however, a partial section is indicated, the remainder of the view being in elevation or plan, the full (surface) line is used, except where there is an opening appearing in both parts of the view; in this case, the dash and dot would be used where the line crosses the opening, and the full line where it crosses the solid portion.

Dimension lines are lines drawn to show limits to which dimensions apply; they are ended with an arrowhead, put in freehand, and the arrowheads should always touch the lines which limit the dimension, thus $\vert\!\longleftarrow 2\frac{1}{2}'' \longrightarrow\!\vert$ Never thus: $\vert \longleftarrow 2\frac{1}{2}'' \longrightarrow \vert$ A short dimension may be indicated thus: $\rightarrow\!\vert \frac{3}{32}'' \vert\!\leftarrow$ or $\rightarrow\!\vert\,\vert\!\leftarrow \frac{3}{32}''$ placing arrowheads outside of limiting lines.

22. Sections and Section Lining.—In order to show the interiors of objects, they are often drawn in section, and the kind of material of which they are made is often indicated by certain combinations of lines. Unfortunately, there is no universally adopted standard; thus, a certain combination of lines may indicate that the material is cast iron if drawn in one office; in another office this same combination may have been adopted to represent brass; and so on. As far as working drawings are concerned, there is usually no difficulty experienced on account of this diversity of practice, since as a general rule the material is, and should always be, distinctly specified on the drawing in order to prevent any mistake on the part of the workman.

23. The most commonly used combinations of lines for different materials are shown in Plate 1001, in Fig. 5. Steel of all kinds is indicated as shown in view (*a*); (*b*) shows the sectioning employed for wrought iron. Cast iron is usually sectioned as shown in (*c*), and this type of cross-sectioning will be used for *all* materials unless it is deemed advisable on complicated drawings to designate kind of material by character of cross-section, in which case the standard sections here shown will be used. Brass and other similar copper alloys are sectioned in the manner shown in (*d*). For lead, Babbitt, and similar soft metal, the sectioning shown in (*e*) is extensively used. Wood, when cut across the grain, is usually sectioned as shown in the upper half of (*f*), and when cut along the grain, as shown in the lower half. Wood is also frequently indicated on a drawing by section lines, even when it is not a section. Glass and stone, when in section, are often indicated in the manner shown by the upper half of (*g*); when not in section, they are frequently drawn as shown in the lower half. Concrete may be indicated as in (*h*); (*i*) gives a common representation of leather. Rubber and wood fiber are sectioned as shown in (*j*); firebrick, as shown in (*k*); and water, as shown in (*l*).

24. Sections of material that appear too thin on a drawing to be conveniently sectioned, or when it is desired to make the section very prominent, are often blackened in, as shown in

Fig. 4. In order to separate different pieces, a white line is then usually left between them. Black sections are most frequently employed for sectional views of structures composed of plates and rolled sections, such as **I** beams, angle irons, bulb angles, rails, **Z** bars.

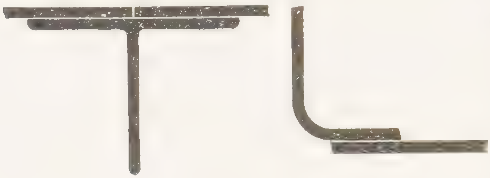


Fig. 4

25. On many sectional views, it will be noticed that the section lines do not run in the same direction. This invariably means that there is more than one piece in the section given. Thus, in Fig. 5, it will be seen that the section lining shown at *b*, *b* is at a right angle to the other section lining. It is the general rule among draftsmen that all parts of the same piece shown in section must be section-lined in the same direction, irrespective of the continuity of the section. Thus, referring again to Fig. 5, the fact that all section lining marked *A* is in the same direction immediately establishes the fact that this part of the view is a section of the same piece. Likewise, since the sectioning shown at *b* and *b* runs in the same direction, it follows that *b* and *b* are sectional views of one piece, which is separate from *A*.

The above rule governing the direction of section lines is always adhered to when possible; when any departure is necessary, care is taken to prevent ambiguity. Where only the sectional view is given, it is often very difficult to understand the drawing, and sometimes a violation of the above rule will be the cause of misunderstandings. For example, in Fig. 6 (*a*), since the section lines of *a* and *a′*, and also those shown at *b* and *b′*, are respectively in the same direction, any one would be perfectly justified in assuming that *a* and *a′* indicated a sectional view of a rod fitted with a solid bushing *b b′*. Furthermore, since *c*, *c* and *c′*, *c′* are sectioned the same way, the conclusion that they were the jaws of a forked rod would be justifiable.

Fig. 5

Referring now to view (*b*), it is seen that *b* and *b′* are separate brass boxes; the part *a′* is seen to be separate from the cap *a*, and the note "*Rods Removed*" indicates that *c* and *c′* represent two separate rods. The way the sectional view should have been section-lined to correspond to the front view shown in (*b*) is given in Fig. 6 (*c*). By a study of the perspective view of this machine detail, which is shown in Fig. 7, the points brought out in connection with the sectional views will be more easily understood.

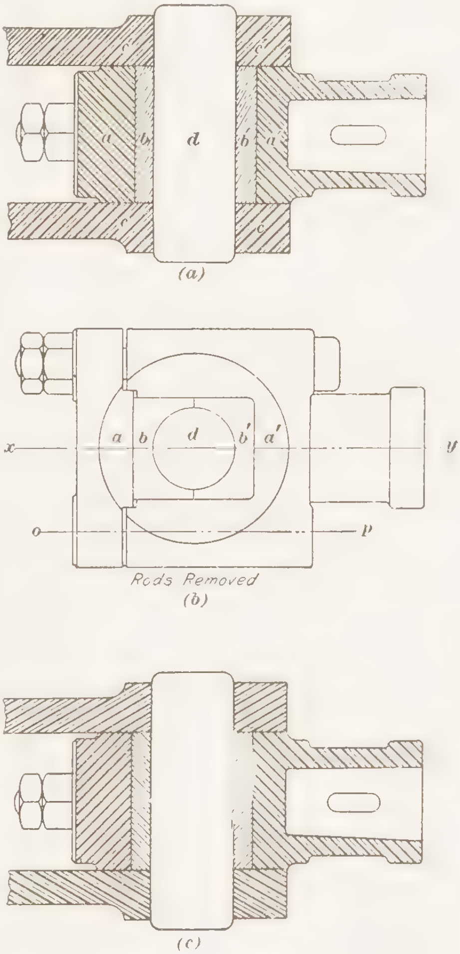


Fig. 6

26. When a cutting plane passes through the axis of a shaft, bolt, rod, or any other solid piece having a curved surface and located in the plane on which the section is taken, it is the general practice not to show such solid pieces in section, but in full. Thus, in Fig. 6 the sectional view (*a*) is taken on the plane represented by the line *x y*, in view (*b*), which passes through the axis of the pin *d*. This pin is shown in full, however, in views (*a*) and (*c*). The practice here shown is rarely departed

from by experienced draftsmen, since it makes a drawing easier to read and also saves considerable time in making the drawing.

27. Fig. 6 also shows another feature that is frequently met with in shop drawings. It is seen in the front view (*b*) that no bolt is shown in the lower half of the object. A center line *o p* is drawn in, however, which indicates to the workman—who reasons from the symmetry of the object in respect to the center line *x y*—that the lower half of the object is to be supplied with a bolt placed in the plane given by the center line *o p*. In case of symmetrical work, draftsmen will frequently complete only one-half of the view and merely indicate the other half by a few lines or not at all, trusting to the judgment of the workman for a correct reading of the drawing. In the best practice, a note is made on the drawing calling attention to the fact that the indicated portion of the view is a duplicate of the completed portion.

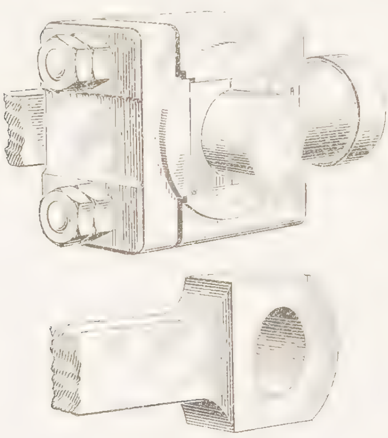


Fig. 7

SUGGESTIONS FOR MAKING THE PENCIL DRAWING

28. After the border lines of the plate are drawn as explained in *Geometrical Drawing*, Part 2, the five figures, or groups of figures, can easily be arranged on the plate by means of the dimensions, which locate the positions of the views with respect to the border lines.

In ordinary practice, the pencil drawing is made with a sharp, hard pencil, and shows outlines only, all black masses or section lining being left to be put in with ink on the tracing, which is to be made later. In Fig. 1, only the heights of the blackened-end sections are given; the widths and thicknesses may be drawn to proportions relative to those shown on the sample

copy. In actual practice, the detail dimensions of such sections are obtained from tables furnished by the manufacturers of the structural iron and steel used in the construction.

In drawing Fig. **3**, the center lines should be drawn first, thereby locating the centers of the various circles.

In drawing Fig. **5**, it is necessary only to locate and draw the outlines of the squares and rectangles, as the section lining in these, as well as in Fig. **1** (*a*), will be filled in and drawn direct in ink on the tracing. The title in the lower right-hand corner of the tracing and the dimension figures and dimension lines should be penciled on the drawing before it is traced. The inscriptions (*a*), (*b*), (*c*), etc., under the views are merely for convenience, and are not to appear on the drawing; all other lettering should be put on carefully. Full instructions in regard to lettering are given in *Geometrical Drawing*, Part 1.

TRACING THE DRAWING

29. The directions here given for making tracings are of a general nature and will apply to all the tracings required in this course of study.

It will be observed that the tracing cloth has two sides of different finish. One is known as the glossy side and the other as the dull side. After the pencil drawing has been carefully finished and all dimensions have been checked with the scale and found accurate, place a sheet of tracing cloth over the drawing, putting thumbtacks in each corner, and smoothing out all wrinkles. Either side of the tracing cloth may be used for the inking in, but the glossy side is preferable because it gives a better appearance to the finished drawing and will not soil so easily. Lines drawn on the glossy side can also be erased more easily. The dull side has its advantage when it is found necessary to do pencil work on the tracing. When a tracing is to be photographed it is better to make it on the dull side. There are no rules governing the matter, and the draftsman uses the side that will best suit the work, or his individual taste, or conform to the practice of the drafting room in which he is employed.

In order that it may take the ink properly, the surface of the tracing cloth must be free from all dirt or grease. A little powdered chalk rubbed over the entire surface with a soft, clean rag, and then wiped off, will serve as an effective cleaning. Dealers in drawing materials offer, for the same purpose, a *tracing powder*, or *pounce*, put up in convenient tin shakers. The handling of tracing cloth with perspiring or greasy hands will make the surface unsatisfactory for the inking in and consequently the chalk powder should be rubbed over it whenever needed.

30. In making small tracings that can be finished quickly, it is the usual practice to trace the center lines first. On tracings that are not likely to be completed the day they are begun, it is safer to ink the center lines in only such a part of the drawing as can be finished in a short time. The reason for this is that the tracing cloth expands and contracts with the varying amounts of moisture in the atmosphere, so that if center lines are drawn in various parts of a large tracing, by the next day they may be so much out of place, as compared with the pencil drawing, as to be useless.

After as many center lines are inked as seems advisable, the circles and curves are traced. It will be found much easier to draw a straight line from the end of a curve or to connect two curves with a straight line than to draw the straight lines first and then join the curves to these. In fact, the latter method is very awkward and sometimes impossible. Care must also be taken when tracing curves that they are not drawn beyond the points at which they are to join the straight lines, otherwise poor and easily noticed joints will be the result.

31. After the center lines and curves have been traced, the horizontal lines should be drawn with the **T** square, those at the top of the sheet being drawn first, the work proceeding downwards. Next, with the triangle against the upper edge of the **T** square, draw the vertical lines, and then the inclined lines.

In order to arrive at a proper thickness of line, try the ruling pen on the edge of the tracing cloth that is outside the trimming line, or on a separate piece. Do not begin to draw any lines

on the tracing until the pen works freely and smoothly and produces lines of the right thickness. No other working or construction lines than those shown on the sample copy should be inked in on the tracing. In the case of blackened sections such as shown in Figs. 1, 2, and 3, the outlines should be inked in first and the enclosed area afterwards blackened with the lettering pen. When the rest of the tracing has been completed, the title and all lettering and dimension figures should be inked in.

ERASING

32. Erasing on Tracing Cloth.—To make erasures on tracing cloth, the cloth should be laid on a smooth surface and rubbed gently and patiently with the eraser until all traces of the lines have disappeared; a rotary motion imparted to the eraser often facilitates the operation. The gloss on the tracing cloth, which may be destroyed by the rubbing, can be renewed by applying powdered soapstone with a piece of chamois skin and finishing the spot by rubbing with the chamois skin alone.

Another method by which ink spots may be removed from tracing cloth is by the use of spirits of camphor applied with a soft cloth. This method does not damage the texture of the tracing cloth.

33. Erasing on Drawing Paper.—When it is found necessary to erase an ink blot or a line that has been inked on drawing paper, only an ink eraser, or sand rubber, should be used. After the erasure is made, the roughened part of the surface of the paper should be smoothed by rubbing with some hard substance, as a piece of ivory or the handle of a knife.

INSTRUCTIONS AND DEFINITIONS

34. Before beginning work on the next plate, further instructions and definitions are necessary.

35. Numbering of Drawings.—When a drawing is made it is given a number by which it can be identified; this is called the **sheet number** or the **plate number**, as Plate 1002.

When a detailed drawing is finished, a number called a **part number** is given to each of the details or parts, and by this number the part represented is thereafter identified. Such numbers are placed on the drawing as near to the representation of the part as is convenient. In all the plates that follow, the part number enclosed in a circle $\frac{3}{8}$ inch in diameter, as 1 will be placed near the view of the part to which it refers.

Part numbers begin at 1. Be careful to place them so that they will not interfere with dimensions, center lines, or surface lines. These part numbers will be referred to in the material list, as explained later.

36. Pattern Numbers.—All machine parts that are made from castings must first have a pattern, and the common practice is to have the draftsman note, in the proper place on the drawing, that a pattern is to be made and give it a number by which it can be known and referred to. This pattern number, which is assigned the first time the part appears on the drawing, will be the number of the drawing, or the plate number, with a letter annexed, thus: Part 1, Plate 1002, is made of cast iron and its pattern number will be 1002–A. This number serves as an immediate means of identification and gives any person who handles the pattern the number of drawing upon which all dimensions can be found. This pattern number is called for in the material list of which an explanation follows.

37. Material List.—All detailed working drawings have a list of materials placed at some convenient part of the drawing; this is the list of parts shown on the drawing giving the number of parts necessary to complete the apparatus shown, the material from which they are made, and a note calling for patterns when they are necessary. This material list is best placed above—and is practically an extension of—the title. The list is divided into six columns which, taken together, are 4 inches wide, the same width as the main title previously described. Column 1, at the left-hand side, is made $\frac{1}{4}$ inch wide and is the quantity column, showing the number of parts required in order to complete the part detailed; column 2 is

made $1\frac{5}{8}$ inches wide, and gives the common shop name of the part; column 3 is $\frac{1}{4}$ inch wide, and shows the part number; column 4 is made 1 inch wide, and shows the material from which the part is to be made; column 5 is made $\frac{5}{8}$ inch wide, and is reserved for the word "pattern" when one is necessary; column 6 is made $\frac{1}{4}$ inch wide, and contains the letter by which the pattern will be known when called for, it being preceded by the number of the drawing. It frequently happens that patterns made for one machine can be used to produce castings for another machine under construction. In such cases the pattern would be designated in the material list by the number and letter first assigned to it. It is not at all necessary to put a heading over these columns, as the use which is made of them soon fixes their object in the mind of the draftsman.

The material list is divided into sections by horizontal lines $\frac{3}{16}$ inch apart. Standard details, such as machine screws, bolts, nuts, washers, keys, and similar parts, have part numbers assigned to them, but are seldom detailed on the drawing, the material list giving all the information that is necessary in order that they may be supplied to the person who is to assemble the part.

The material list is best arranged in such a way that the lowest number is put at the bottom of the list. The reason for this is to permit the adding of another detail, if such should become necessary, or, in other words, placing the parts in this order in the title permits the extension upwards of the space occupied by the latter as desired, some titles listing only a few details and others many, according as the machine drawn is more or less complicated.

38. Positions of Views.—The main view or elevation once having been located, the right-hand view of the object will be shown at the right of the elevation, the top view at the top, bottom view at the bottom, etc. This method of location of views is technically known as *third-angle projection* and is more generally used than *first-angle projection*, which differs from it by having the right-hand view of the object placed on the left-hand side of the main plan, the bottom at the top, etc.

An explanation as to the use of the first-angle and third-angle projection will be given later on in *Practical Projection*. Either plan may be used, but each drawing office has a standard practice that must be followed. In the plates which follow, third-angle projection is adopted as standard.

PLATE 1002, TITLE: SIMPLE MACHINE DETAILS

39. Plate 1002 is intended to show how to make a regular working drawing of simple machine details, and the necessary directions for drawing each object will be given. Because those having little or no acquaintance with machinery often find it difficult to obtain an accurate idea of the appearance of an object from a mechanical drawing, perspective representations of the objects to be drawn are given in the text. These should be studied carefully before the drawing is undertaken.

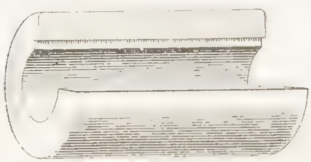


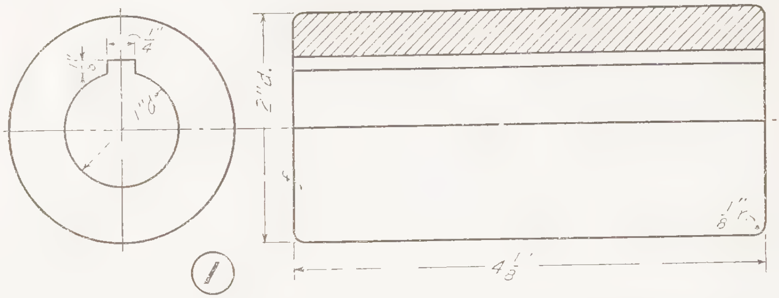
Fig. 8

40. Part **1** represents an ordinary box coupling, which is a cast-iron cylinder fitting over and connecting the two ends of a shaft. The depth of the keyway is cut half into the coupling and half into the shaft ends not here shown.

The views given on the plate are an end elevation and a sectional elevation. In the end elevation all outlines are seen, but in a side elevation the keyway and inside diameter would not be visible, and ordinarily would be represented by dotted lines.

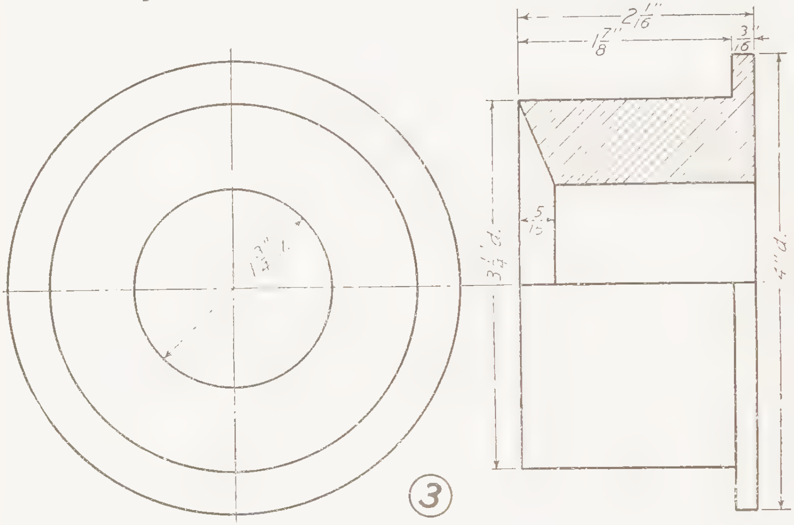
A more common method is to cut away a quarter section, drawing the interior edges with full lines, and then section-line the cut to show the material from which the part is to be made. Such a view is called a **sectional elevation.** In Fig. 8 is shown a perspective view of the object represented in Part **1.**

To draw the views shown on the plate, begin by locating a horizontal center line 2 inches below the upper border line, and a vertical center line for the end elevation, $1\frac{3}{4}$ inches from the left-hand border line.



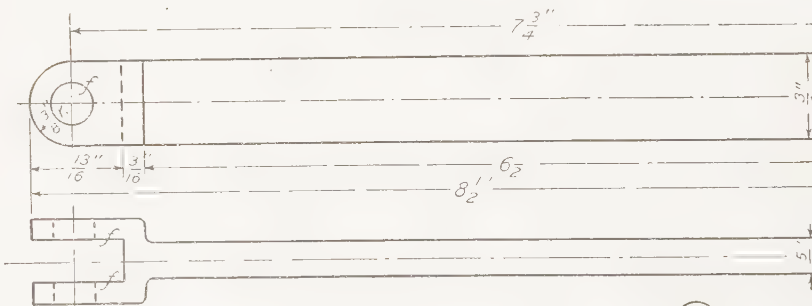
1

"f" all over



3

"f" all over



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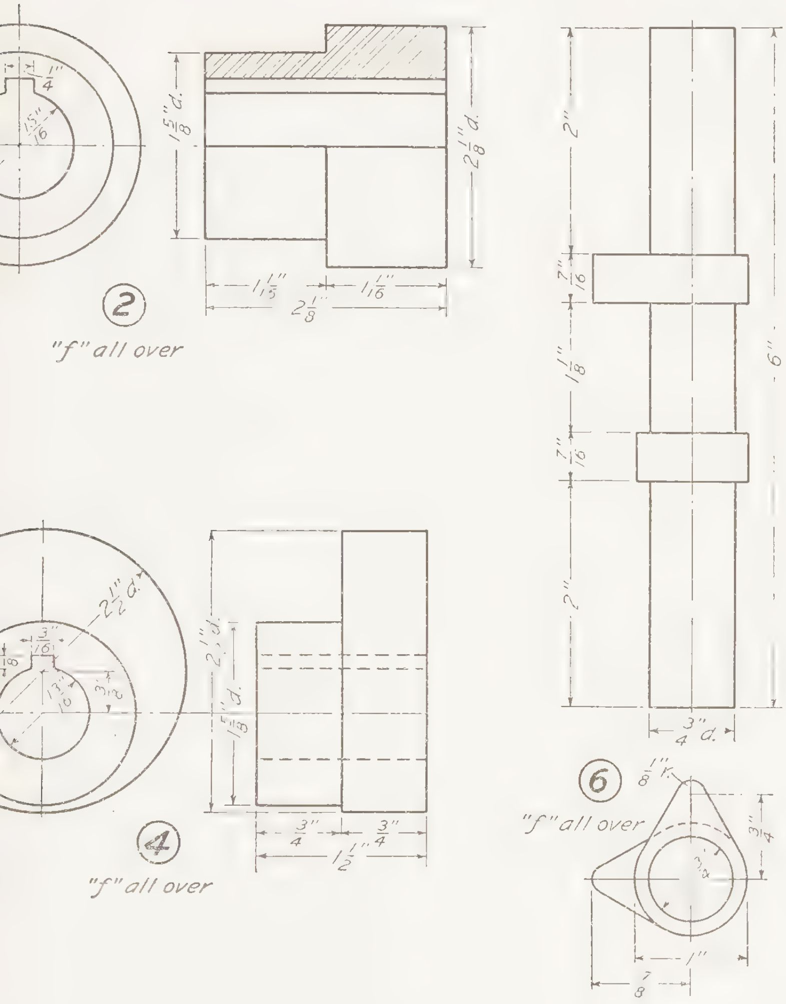

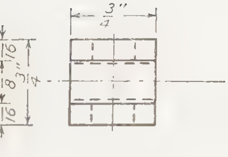

1	Cam Shaft	6	Steel		
1	Link	5	Steel		
1	[illegible]	4	Steel	Pattern	D
1	[illegible]	3	Brass	Pattern	C
1	Gear Pinion Blank	2	Steel	Pattern	B
1	Box Coupling	1	Cast Iron	Pattern	A

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From the intersection of the two center lines draw a circle 1 inch in diameter for the bore of the coupling, and from the same center describe a circle 2 inches in diameter, this dimension being obtained from the sectional elevation.

To draw the keyway, lay off a distance of $\frac{1}{8}$ inch each side of the vertical center line and draw two lines to intersect the inner circle, at which points the depth of the keyway may be laid off and a horizontal line drawn completing the keyway and also the end elevation.

To draw the sectional elevation, locate the left edge $1\frac{1}{2}$ inches from the vertical center line, and from this point measure off the length, $4\frac{1}{8}$ inches, on the horizontal center line, and through these points draw vertical end lines of indefinite length. With the T square project lines tangent to the outer circle of the end elevation and project the corners of the keyway across the sectional elevation. With the bow-pencil set to a radius of $\frac{1}{8}$ inch, put in the rounded corners.

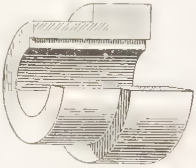

FIG. 9

41. Part **2** represents the blank or casting for a gear pinion ready for the cutting of the teeth.

Fig. 9 gives a clear idea of its shape.

Locate the views by drawing a horizontal center line 2 inches below the upper border line, and through this line draw a vertical center line $7\frac{1}{2}$ inches from the right border line. The end elevation is to be drawn from the dimensions given and in a similar manner to the end elevation of the coupling.

Locate the left edge of the sectional elevation $1\frac{5}{8}$ inches from the vertical center line of the end elevation, and from this point lay off the two divisions of $1\frac{1}{16}$ inches each, drawing vertical lines of indefinite length through these points. The horizontal lines of the sectional elevation are now projected from the end elevation to complete the figure, in the manner described for Part **1**.

42. Part **3** represents two views of a gland, or the outer portion of a stuffingbox, as illustrated in Fig. 10. It fits into the bore of the stuffingbox and compresses the packing.

To draw the views, locate a horizontal center line $6\frac{1}{4}$ inches from the upper border line; and $2\frac{3}{4}$ inches from the left-hand border erect a vertical center line. From the intersection of these lines describe three circles of the dimensions given, two of which are found in the sectional elevation. Draw the left edge of the sectional elevation $2\frac{1}{2}$ inches from the vertical center line, and from this space off and draw the vertical divisions with the dimensions given and project the horizontal outlines from the end elevation to the sectional elevation. A diagonal line drawn to represent a conical surface completes the view.


FIG. 10

43. Part 4 shows an eccentric, or modified form of crank, illustrated in Fig. 11, that is extensively employed to give the desired motion to the slide valve of a steam engine.

On the plate it is represented by a front and side elevation. The horizontal center line is located 6 inches from the bottom border line and the vertical center line $7\frac{1}{4}$ inches from the right border line.

In the end elevation, it should be noticed that the center for the outer circle is $\frac{3}{8}$ inch above the center of the inner circles. The left-hand edge of the side elevation should be located $1\frac{7}{8}$ inches from the vertical center line of the end elevation. No special instruction is necessary to draw these two views, as they are similar to those that have preceded them except that on the side elevation the interior parts are indicated by dotted lines.


FIG. 11

44. Part 5 of the plate represents three views of a link or connecting bar with forked ends, illustrated in perspective in Fig. 12.

Draw the center line of the elevation $1\frac{5}{8}$ inches above the bottom border line and the center line of the plan 3 inches above the same border line. The vertical left-hand center line is located $1\frac{1}{8}$ inches from the

left-hand border line and the center line of the other end is drawn from the dimension given. Locate the center line for the end view of the link $1\frac{1}{2}$ inches to the right of the nearest vertical center line in the elevation.

FIG. 12

Begin drawing the plan view by describing arcs for the rounded ends of the links and circles for the holes and connect the arcs with horizontal lines.

From each end lay off measurements of $\frac{13}{16}$ inch and $\frac{3}{16}$ inch, at which points draw vertical full and dotted lines to represent the outside and inside edges of the forks.

Now draw the front elevation by first projecting lines from the outside shoulder of each fork and intersecting these projected lines by two horizontal lines laid off $\frac{5}{32}$ inch each side of the horizontal center line. The vertical dimensions of the forked part may now be laid off each side of the horizontal center line from the dimensions given and the rounded corners or fillets put in with arcs of $\frac{1}{16}$-inch radius.

The end view may be laid off by drawing two vertical lines $\frac{3}{8}$ inch each side of the vertical center line and projecting the thickness of the forked parts from the front elevation. The horizontal dotted lines represent the thickness of the bar and the vertical dotted lines the holes in the forked ends.

45. Part 6 is a drawing of a cam shaft illustrated in Fig. 13. A cam is a rotating piece, either non-circular or eccentric, used to convert rotary into reciprocating motion.

FIG. 13

The cam is represented by a plan and an end view and is drawn as follows: Draw a vertical center line for both views at a distance of $1\frac{9}{16}$ inches from the right-hand border line, and a horizontal center line for the end view $4\frac{9}{16}$ inches above the bottom border line. Describe a circle with a $\frac{3}{8}$-inch radius

to represent the cam-shaft and another circle with a $\frac{1}{2}$-inch radius. Locate on the horizontal center line a point $\frac{3}{4}$ inch to the left of the vertical center line, and, on the vertical center line, a similar point $\frac{3}{4}$ inch above the horizontal center line. From these points describe arcs with a $\frac{1}{8}$-inch radius. Tangent to the arcs draw the tapering sides of the cams. The part of the cam that is hidden is shown in dotted lines. The plan view is now drawn by locating the upper end of the shaft $\frac{15}{16}$ inch from the top border line. Lay off all the vertical divisions from dimensions given and draw lines through these points. Project the lines representing the diameter of the shaft and the edges of the cams from the end view.

Put in all dimension lines and dimensions and pencil in the title and material list.

46. The drawing is now ready to be traced. As the tracing will take a comparatively short time, all center lines may be traced first, then the circles and arcs, and finally the straight lines.

The dimension lines may then be added and arrowheads made to extend exactly to the lines from which the dimensions are taken. Sometimes dimension figures occur in places that are to be sectioned and it is therefore advisable to put the dimensions in first. On the plate, the notes "*f*" *all over* indicate that the entire surfaces of the objects shown are to be machine finished.

EXPLANATIONS

47. Details That Should Appear on Pencil Drawings. In the following pages many of the illustrations in the text may be considered to represent the pencil drawings in the form in which they would appear when prepared for tracing. Practice varies among draftsmen in regard to the completeness of such drawings. Many draftsmen consider that these drawings are only to indicate the location of the various lines, hence lines that are to be dotted on the tracing are often drawn full, because they can be drawn more quickly, and construction lines are left on, the lines being properly dotted and unnecessary lines

omitted when the tracing is made. This method may be safely followed by experienced draftsmen when tracing their own pencil drawings, but the safest way is to make such distinctions between full and dotted lines on the pencil drawing that it can afterwards be traced without hesitation and confusion. It is also well to erase on the pencil drawing such construction lines as are not to appear on the tracing. A little extra time and care given to the line work on the pencil drawing will be fully made up for by the increased rapidity with which the tracing can be made.

48. Conventional Methods of Representing Screws. The next plate to be drawn consists of representations of screws, bolts, etc., the first eight figures showing the conventional methods of representing screws. The actual construction and projection of a screw thread are similar to the construction of a helix, as shown in Problem 26, *Geometrical Drawing*, Part 2; but in order to save the time required to locate the points and to trace in the curves, the following conventional methods of representing screw threads are universally employed, except, perhaps, in the case of screws of very large diameter and pitch. Before drawing the figures representing screws it will be necessary to give a brief description of the general principles governing the laying out of such threads.

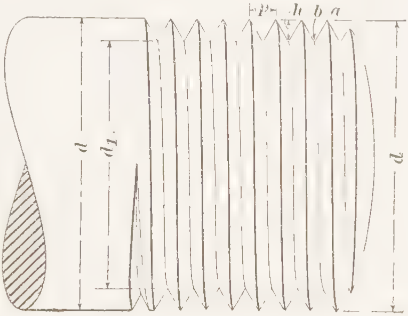

Fig. 14

49. A plain screw thread on the end of a bolt is shown in Fig. 14. The outer edge *a* where the sides of the thread meet is called the **point** of the thread; and the inner point *b* where the adjacent sides meet is the **bottom** of the thread. The **diameter** of a screw is the diameter measured over the points of the thread; that is, it is the same as the diameter *d* of the bolt before the thread was cut. The **root diameter** is the distance through

the core of the screw from bottom to bottom, as d_1. The **height** or **depth** of a thread is the vertical distance h from the bottom to the point, or top edge, of the thread.

50. A **single thread** has one spiral groove cut around the bolt, leaving one spiral ridge, or thread, as shown in Fig. 14. A **double thread** has two spiral grooves cut around the bolt, side by side, leaving two parallel spiral ridges, or threads. Fig. 15 shows a double thread. One thread is cut farther along the bolt than the other to show how the first thread is cut. A **triple thread** has three spiral grooves, and consequently three spiral ridges, or threads. If two strings are wound spirally at the same time around a pencil, the strings being kept side by side, they will represent a double thread; if three or four strings are used, a triple or quadruple thread will be illustrated.

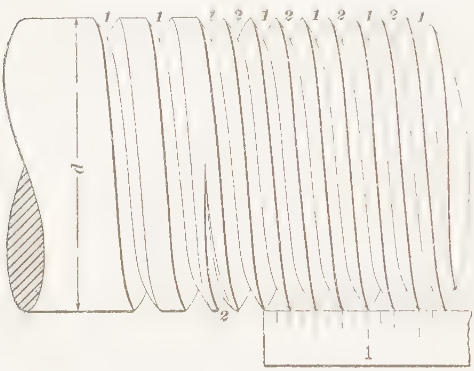

Fig. 15

51. The **pitch** of a thread is the distance, measured parallel to the axis of the bolt, from the point of one thread to the point of the thread *next* to it, as p in Fig. 14. The **lead** of a thread is the distance, measured parallel to the axis of the bolt, from a point on a thread to a corresponding point on the *same* thread when the thread has made a complete turn around the bolt. In a single-thread screw, the pitch and the lead are equal; in a double-thread screw, the lead is twice the pitch; in a triple-thread, it is three times, and in a quadruple-thread it is four times the pitch of a single-thread screw. This is illustrated in Fig. 16.

52. To increase the traverse of a screw the thread must be made of greater lead. If a single thread were increased proportionately in height and width to correspond with the increase in the lead of a screw, too much metal would be cut away and

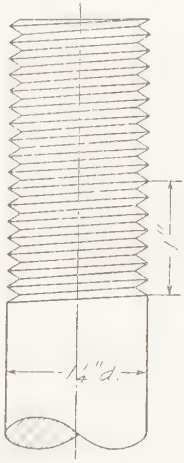

Fig. 1

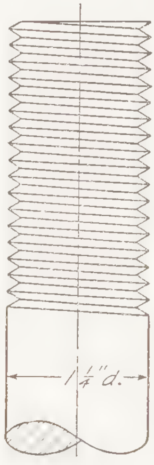

Fig. 2

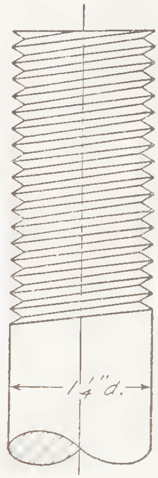

Fig. 3

Fig. 4

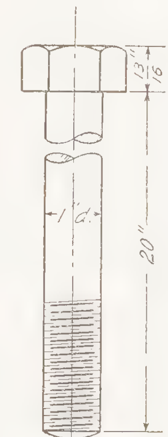

Fig. 9

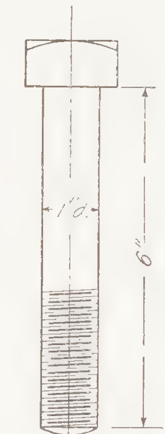

Fig. 11

Fig. 13

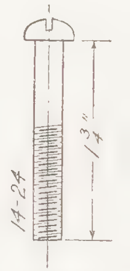

Fig. 15

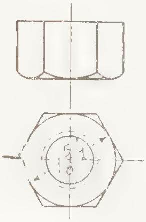

Fig. 10

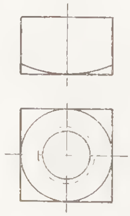

Fig. 12

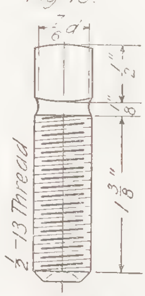

Fig. 14

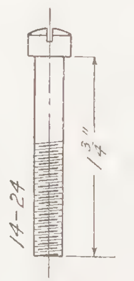

Fig. 16

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Fig. 6

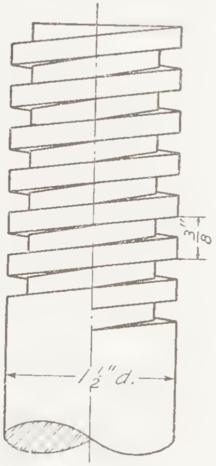

Fig. 7

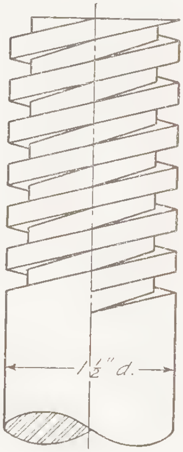

Fig. 8

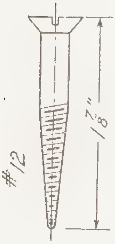

Fig. 19.

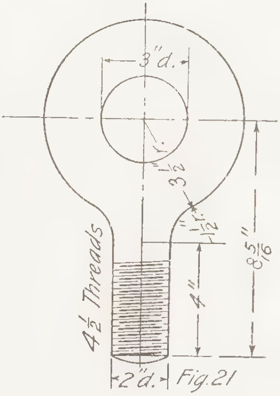

Fig. 21

Fig. 23.

Fig. 24

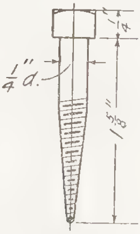

Fig. 22

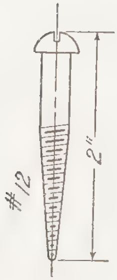

Fig. 20.

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the screw would be weakened, as shown by the dotted lines in Fig. 17, unless the rod was made larger in diameter. For this reason, double, triple, or quadruple threads of less depth are used.

A thread is said to be **right-handed** when the piece on which it is cut can be screwed into a nut by turning in the direction

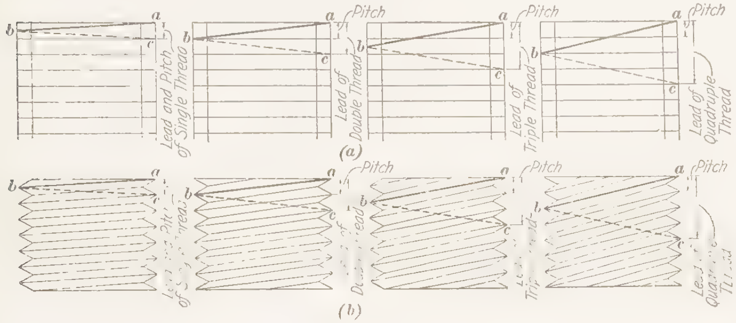


FIG. 16

of the motion of the hands of a watch; but if the piece must be turned in the opposite direction, the thread is **left-handed.** Threads are usually right-handed. If a piece is threaded right-handed, the nut to fit it must be threaded right-handed.

PLATE 1003, TITLE: DETAILS

53. On plate 1003, Figs. **1** to **8**, constituting the upper row of figures, are to be drawn full size. Figs. **9, 10, 11, 12, 13, 23,** and **24** are to be drawn half size, or to a scale of 6 inches = 1 foot. Figs. **14, 15, 16, 17, 18, 19, 20,** and **22** are to be drawn full size, and Fig. **21** is to be drawn one-fourth size, or to a scale of 3 inches = 1 foot.

FIG. 17

To locate the upper row of views on this plate, draw a faint horizontal line $1\frac{1}{8}$ inches below the upper border line and locate the upper ends of the views along this line. Draw another

horizontal line $3\frac{3}{4}$ inches below the first line, to limit the lengths of these views. Leave a space of $\frac{3}{4}$ inch between Fig. **1** and the left-hand border line, and spaces of $\frac{13}{16}$ inch between Figs. **1** to **7**, and $\frac{7}{8}$ inch between Figs. **7** and **8**.

54. Fig. **1** represents a single **V**-thread screw $1\frac{1}{4}$ inches in diameter and having seven threads to the inch; that is, the pitch is $\frac{1}{7}$ inch.

In Fig. 18 is shown the method of constructing the thread. Draw an elevation of a cylinder $1\frac{1}{4}$ inches in diameter and having

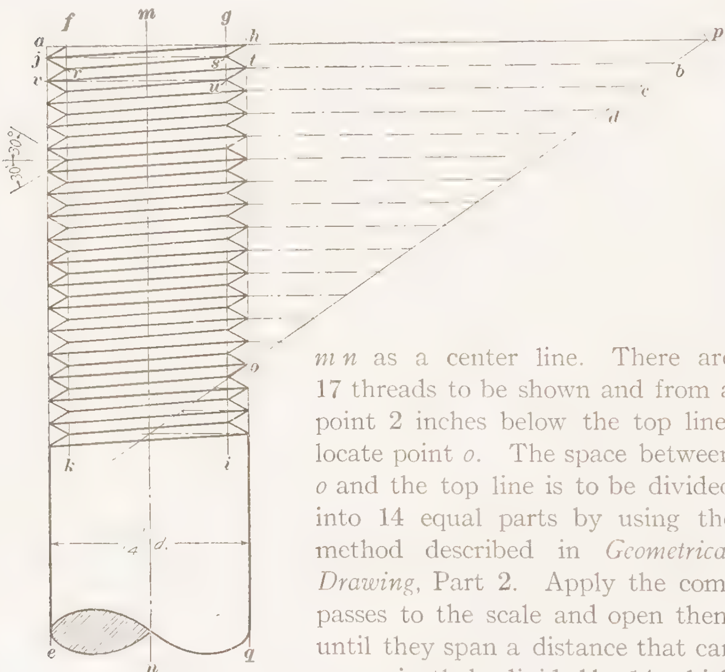


Fig. 18

m n as a center line. There are 17 threads to be shown and from a point 2 inches below the top line, locate point *o*. The space between *o* and the top line is to be divided into 14 equal parts by using the method described in *Geometrical Drawing*, Part 2. Apply the compasses to the scale and open them until they span a distance that can conveniently be divided by 14, which is the number of threads in 2 inches. In this case this distance is $3\frac{1}{2}$ inches; and then with this length as a radius and using *o* as a center, strike an arc intersecting the extended horizontal line *a h* at *p*. Connect *o p* by a straight line, and by using the scale and a sharp-pointed pencil set off on this line the 14 divisions, as *p b*, *b c*, and *c d*, which are $\frac{1}{4}$ inch on

the full-size scale. With the scale in the same position, point off to the left of *o* three $\frac{1}{4}$-inch spaces for the three extra threads. Draw from each of these dividing points, with the aid of a **T** square, faint horizontal lines intersecting the vertical line *h q*. With the 30° triangle along the edge of the **T** square, as shown in Fig. 19, draw inclined lines from *h* and *t* intersecting at *s*, as shown in Fig. 18.

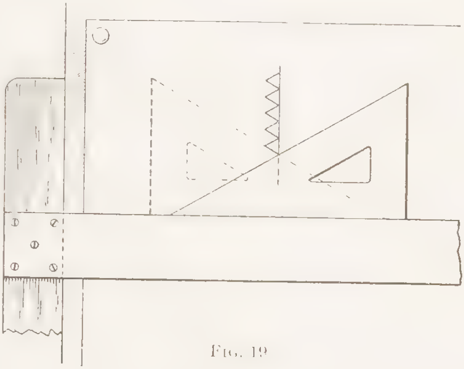


Fig. 19

Through the point *s* draw a vertical line *g i* to serve as a limit for the bottoms of the threads. Finish the remaining threads on the right-hand side in the same manner. From the points *s* and *u* draw horizontal lines cutting *a e* in *j* and *v*. From the points *j* and *v*, with a 30° triangle along the edge of the **T** square, draw inclined lines similar to those on the right side to intersect at *r*. Through the point *r*, draw a vertical guide line *f k*. Finish the remaining threads on the left side. Connect all the outer edges of the threads by lines, as *h j* and *t v*, which will be parallel if the work has been accurately done. Connect all the inner points representing the root of the threads by lines, as *r s*, which will also be parallel.

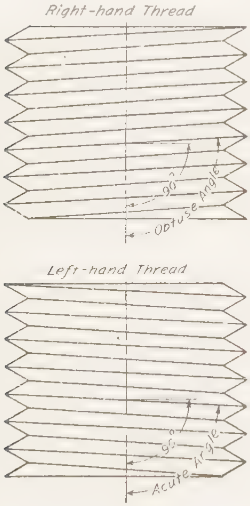


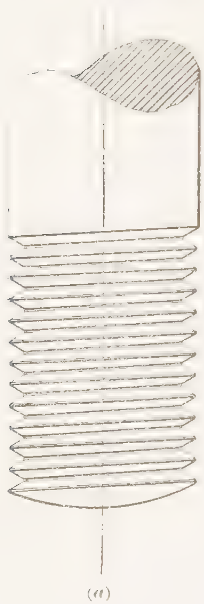
Fig. 20

The threads are cut on the ends of straight rods and only a portion of the rod is shown; therefore, the conventional method of indicating the break is used; this may be drawn freehand or with the bow-pen. The surfaces of the breaks are shown sectioned as steel.

55. The method for laying out the pitch for single-, double-, triple-, and quadruple-threaded screws is shown in Fig. 16 (*a*). The heavy lines *a b c* indicate the angles, and the light horizontal lines the number of threads to the inch. In view (*b*) the illustration shows the threads on each type of screw completed with one continuous thread accented.

56. Fig. 2 represents a single **V**-thread screw exactly like the preceding one except that the thread is a left-hand thread instead of a right-hand.

To determine whether the drawing of a screw represents a right-hand or a left-hand thread, note that when the axis is vertical, if the lines representing the thread slope downwards from right to left, the screw represented is right-handed. If the threads slope downwards from left to right, a left-hand thread is represented. This is illustrated in Fig. 20, where the view of a right-hand thread shows that the angle between the axis and the thread (the angle being measured to the right of the axis and below the thread) is an obtuse angle, and for the left-hand thread it is an acute angle.



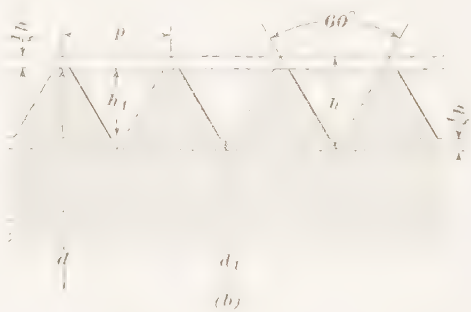


Fig. 21

It is customary to assume that all screws not otherwise marked are right-handed. No further instruction should be necessary for drawing the thread.

57. The **Seller's triangular** or **V thread,** commonly called the **American thread,** or **United States Standard,**

which is used in the United States, is shown in Fig. 21 (*a*). Fig. 21 (*b*) is an enlarged section of the thread. The *angle* between the sides of the thread is 60°. The distance p indicates the pitch of the screw. As shown in the figure, a section of a single thread is an equilateral triangle, the altitude of which is h; to form the United States Standard thread one-eighth the altitude of the triangle is cut off from the apex, and the angle at the root is filled in to a like depth. Hence the *real depth* of the thread h_1 is three-quarters the altitude of the triangle, that is, $h_1 = \frac{3}{4}h$.

58. Fig. 3 represents a **double V-thread screw** $1\frac{1}{4}$ inches in diameter. It has $3\frac{1}{2}$ double threads per inch; that is, the pitch is $1 \div 3\frac{1}{2} = \frac{2}{7}$ inch.

It will be noted that a line drawn at right angles to the axis of the screw will, as shown in Fig. 18, intersect the outside edge of the thread on one side and the bottom of the groove on the other side. This is the case with single-thread screws and applies to Figs. 1 and 2. In Fig. 22 it is seen that a line drawn at right angles to the axis of the screw will intersect the outside edge of the thread on both sides. This indicates a double-thread screw, of which Fig. 3 is a representation. Figs. 18 and 22 show that the spacing of the threads is done by the method given in Problem 6 of *Geometrical Drawing*, Part 2.

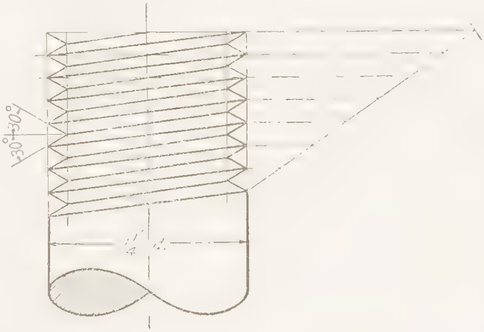


FIG. 22

59. Fig. 4 shows a simpler method of representing a **V**-thread screw. This method has the advantage of making a neat-looking drawing and of being very rapid in delineation. The pitch of the threads is laid off as in the three preceding figures. The heavy lines represent the bottom of the thread.

and their lengths are determined by constructing an equilateral triangle on the pitch distance, as shown in Fig. 23, and limiting the lines to distances between two corresponding vertexes of the triangle. The diameter of the screw is 1 inch and the number of threads per inch is 8.

60. Fig. **5** represents the screw shown in Fig. **4**, but with the heavy lines replaced by light ones. This method has many advantages in making tracings, as it makes the resetting of the pen unnecessary, and the ink does not take so long to dry. The method shown in Fig. **4** will be used for ordinary work; that shown in Fig. **5**, when there are a number of details of the same sort, making a more elaborate representation inadvisable.

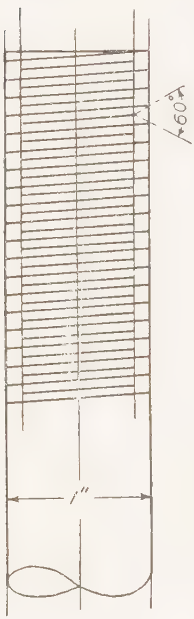


FIG. 23

61. Fig. **6** shows the very simplest method of indicating screw threads. For this purpose it is just as effective as the method employed in Figs. **4** and **5** and is used in cases of hurry or when the appearance of the drawing is considered of less importance, and when the drawing shows a great number of screws.

When screws are represented, as shown in Figs. **4**, **5**, and **6** it is not customary to lay off exact distances between the lines that represent the tops and bottoms of threads. The distances between the lines are made even and of any size that presents a good appearance. This adds, of course, to the rapidity with which a drawing can be made. The right-hand **V** thread is considered as a standard and is always furnished unless some other is specifically called for. When left-hand, double, or multiple threads are wanted, it is customary to place a note near the part detailed, calling attention to the fact.

62. In Fig. 24 is shown a series of diagrams to assist in laying out square-thread single-, double-, triple-, and quadruple-thread screws.

It will be noted that the lead and the pitch of a single-thread screw are the same. The lead always refers to the distance

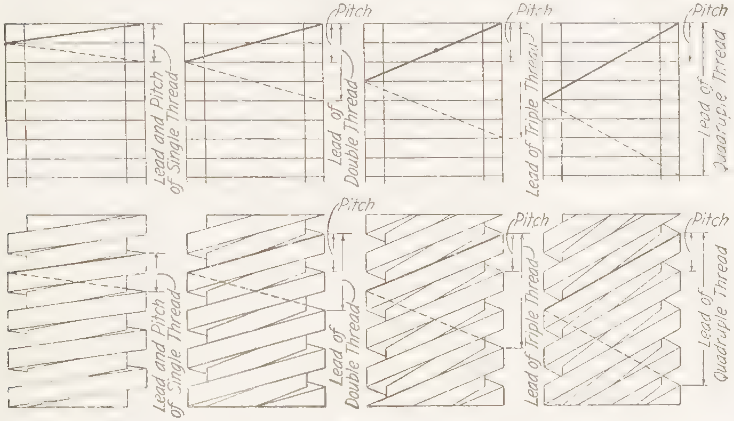


Fig. 24

the thread advances with one revolution of the screw. For double-, triple-, and quadruple-thread screws, the lead increases but the pitch always remains the same, as shown in the illustration. The lead of a double-thread screw is twice the lead of a single-thread screw; that of a triple-thread screw is three times, etc.; and the lead is always made some even multiple of the pitch.

The heavy full and dotted lines in the diagrams indicate one continuous thread for each type of screw.

Fig. 25

63. Fig. 7 represents a square-threaded single-thread screw $1\frac{1}{2}$ inches in diameter and $\frac{3}{8}$-inch pitch. Fig. 25 shows the same kind of screw in perspective. To draw the screw, follow the directions given herewith in connection with Fig. 26.

First draw the center line $m\,n$ $3\frac{7}{8}$ inches from the right border line, then draw a line $a\,b$ at right angles to $m\,n$. The diameter of the screw being $1\frac{1}{2}$ inches, set off on the line $a\,b$ $1\frac{1}{2} \div 2 = \frac{3}{4}$ inch each side of the

center line, and from these points draw construction lines *a d* and *b e* parallel to the center line. The depth of the thread should be one-half the pitch, or $\frac{3}{8} \div 2 = \frac{3}{16}$ inch; hence, set off points *f* and *g* $\frac{3}{16}$ inch from each side of the screw to locate the bottom of the thread, and through the points *f* and *g* draw construction lines *f h* and *g i*. On the line *a d* set off the width of the groove and of the thread, locating the points *a*, *c*, *j*, *k*, *l*, *o*, *p*, etc., each equal to $\frac{3}{16}$ inch, or one-half the pitch. Now draw an edge line *c b*, and parallel to *c b* draw lines *j x*, *k q*, *l r*, etc., through the points *j*, *k*, *l*, etc.

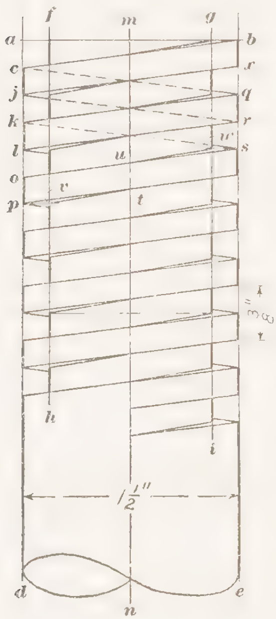


FIG. 26

Draw faint construction lines joining the points *c* and *q*, *j* and *r*, *k* and *s*, etc., to represent the back edges of the threads, and make the parts that are seen, full lines. Draw faint construction lines horizontally from points *j*, *l*, *p*, etc. to the line *f h*, and from the points of intersection with *f h* draw lines, such as *v t*, to the center points of the lower side of the threads, these lines representing the visible bottom lines of the threads. Likewise draw horizontal lines from the points *q*, *s*, etc., to the line *g i*, and from the points of intersection with *g i* draw the lines *u w*, etc. With these construction lines in place, all remaining outlines can now be drawn and the broken end *d e* completed. The method of drawing the remainder of the screw should be apparent.

64. In some drawing offices this conventional method of representing screw threads is further simplified by omitting the lines at *w*, which indicate the upper surface of the threads, as well as those at *v* that represent the lower surface. The threads will then be indicated by a series of parallelograms, such as *c b x j*, *k q r l*, etc.

It will be noticed that the width of the thread and of the groove, measured parallel to the center line $m\,n$, and the depth of the thread are all exactly the same; that is, they are each equal to one-half of the pitch. If a section were taken through the center line $m\,n$, the thread and groove would look like, Fig. 27, a series of squares; hence the term *square thread*.

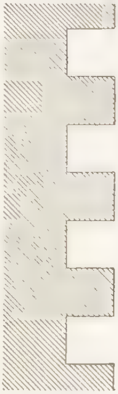


Fig. 27

65. In Fig. 8 is shown a *double square-thread screw* $1\frac{1}{2}$ inches in diameter with $\frac{3}{8}$-inch pitch and a lead of $\frac{3}{4}$ inch. The width and depth of the thread is equal to one-half the pitch, or $\frac{3}{8} \div 2 = \frac{3}{16}$ inch.

In this case there are two threads, the second thread being located between the turns of the first. To draw this, proceed exactly as in the last figure, and follow the directions given herewith in connection with Fig. 28.

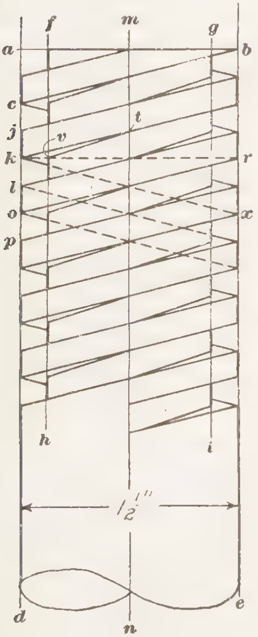


Fig. 28

To get the direction of the line $b\,c$, Fig. 28, which in this figure represents the lower edge of the thread, set off $a\,c$ equal to one-half the lead, or $\frac{3}{4} \div 2 = \frac{3}{8}$ inch, and draw the line $b\,c$. The width of the threads and grooves, and also the depth of the threads, is one-fourth of the lead, or $\frac{3}{4} \div 4 = \frac{3}{16}$ inch.

Through the points k, l, o, etc., draw faint pencil lines $k\,x$, etc., to represent the back edges of the threads and make the parts that are seen in full lines. Through the point k draw a faint horizontal pencil line $k\,r$, intersecting the line $f\,h$ in v, and draw the line $t\,v$, which represents the bottom of the thread. The remainder of the screw should be drawn without difficulty.

66. When a screw thread is hidden by part of the object and it is deemed necessary to show its location, dotted lines

are drawn in one of the three ways illustrated in Fig. 29. Of these methods, (*a*) is the most complete, but (*b*) is the form

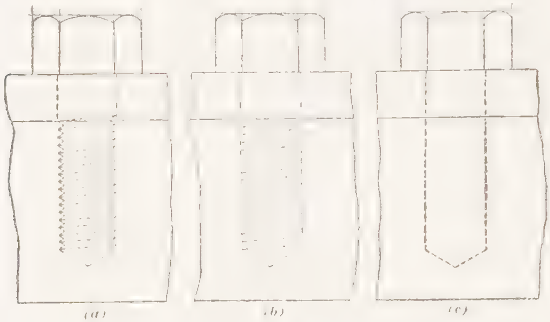


Fig. 29

generally used and is clear. Fig. 29 (*c*) should not be used unless supplemented by a note, as "$\frac{3}{4}''$ stud" or "$1\frac{1}{8}''$ bolt," etc.

67. After the first eight figures of the plate are completed, draw a horizontal line $6\frac{1}{4}$ inches below the top border line and locate the tops of Figs. **9, 11, 13, 15, 17,** and **19** along this line. Lay off on it a point $1\frac{1}{4}$ inches from the left-hand border line, and through this point draw the center line of Figs. **9** and **10.** From this point, also, lay off other points 2 inches apart, through which draw center lines for Figs. **11** to **14,** inclusive. The center lines for Figs. **15** to **22,** inclusive, are $1\frac{7}{8}$ inches apart, and Figs. **23** and **24** are drawn separately.

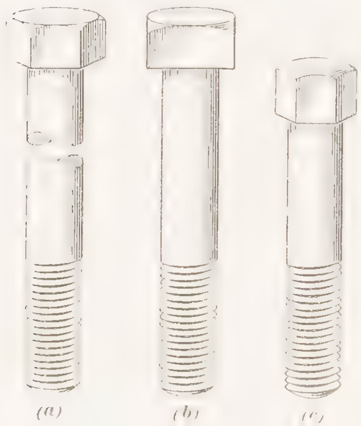


Fig. 30

Figs. **9** and **10** represent a conventional method of drawing a hexagon-head bolt and nut, and in Fig. 30 (*a*) is shown a perspective view of the bolt. The bolt is 1 inch in diameter and 20 inches long, with the threaded portion cut eight threads

to the inch. The head is $1\frac{5}{8}$ inches between the parallel sides, usually referred to as $1\frac{5}{8}$ inches across the flats, and the curve at the lower end of the bolt is drawn with a radius equal to the diameter of the bolt.

To make plain the manner in which the nut and the head of the bolt is laid out, the method that is to be followed will be described in detail. It is not common practice to show more

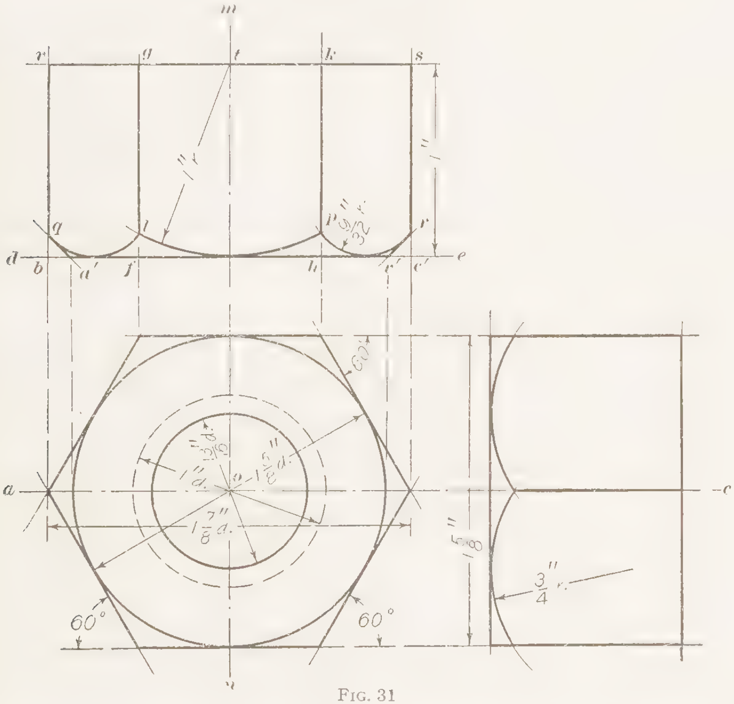


FIG. 31

than one view of either a bolt or nut, the shape being determined by the delineation, but for the purpose of a clearer understanding an exception from this practice has been made in Figs. **10** and **12**, which show the ordinary conventional method of representing nuts.

68. To lay out the nut in Fig. **10**, refer to the detail construction shown in Fig. 31. The vertical center line *m n* having

been located, draw the horizontal center line $a\,c$ $1\frac{3}{16}$ inches above the bottom border line. With the point of intersection o as a center, draw a circle having a diameter of $1\frac{5}{8}$ inches. This is the "across plate" dimension of the nut. The sides of the nut are drawn tangent to this circle by means of the **T** square and the 60° triangle. The dotted circle with 1-inch diameter represents the bottom of the threads and the $\frac{13}{16}$-inch-diameter circle the top of the threads. The upper view of the nut is projected from the bottom view as shown, the line $d\,e$ being located on the plate $\frac{11}{16}$ inch above the center line $a\,c$. To construct the curves which form the top of the nut, draw a circular arc from t as a center, with a radius equal to the diameter of the bolt (in this case 1 inch), tangent to the line $d\,e$, until it intersects $f\,g$ in l, and $h\,k$ in p; find by trial a radius such that arcs can be struck from l to q, and from p to r, and be tangent to $d\,e$; the centers for these arcs must lie at a point half way between the parallel lines $v\,q$ and $g\,l$ and $k\,p$ and $s\,r$. Draw curves for the head of the bolt in the same manner.

The corners $b\,c'$, Fig. 31, are drawn as being parts of a conical surface, the side of which forms an angle of 45° with its axis. Lines $q\,a'$ and $r\,v'$ are then drawn tangent to the curves $q\,l$ and $r\,p$. Where it is the purpose of representing a nut or head in a conventional manner, it is a saving of time to omit these additional lines. A side view of the nut, across flats, is shown in Fig. 31 as a matter of information, but it is not to be put on the plate.

69. Figs. **11** and **12** show the conventional method of representing a square-head bolt and nut, and the bolt is shown in perspective in Fig. 30 (b). Their curves are constructed in much the same manner as those of the hexagon-head bolt, except that they are drawn with a radius twice the thickness of the bolt. Dimensions correspond to those given in Fig. **9**, except the length of the bolt, which is 6 inches; the width of the head is $1\frac{5}{8}$ inches across flats.

Complete information as to the construction of standard bolt heads, nuts, screw heads, etc. is given in Fig. 32. Any dimensions not given in the instructions referring to Plate 1003 will be found on the plate or in Table I.

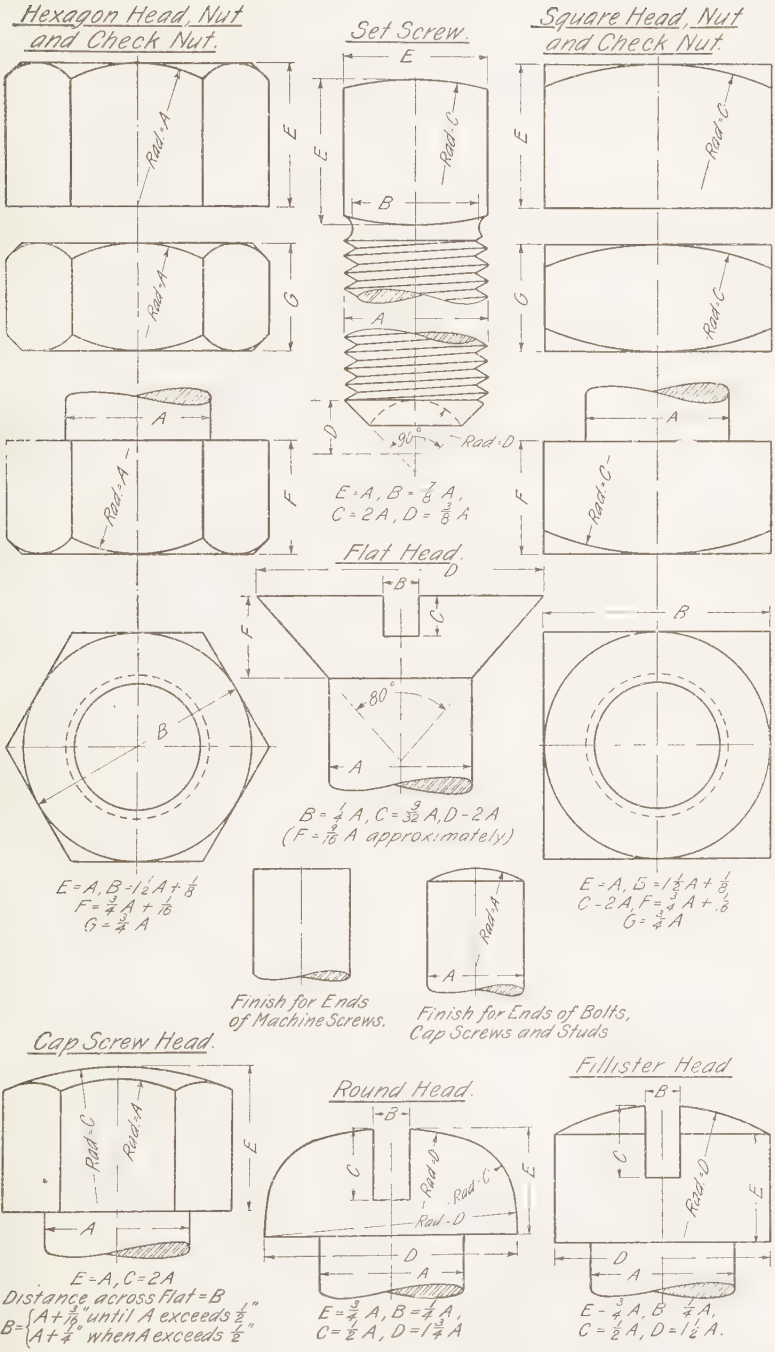
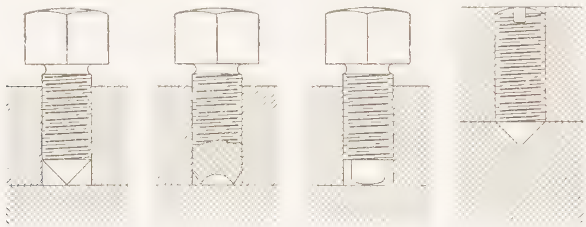

Hexagon Head, Nut and Check Nut.
Set Screw.
Square Head, Nut and Check Nut.
Rad.=A
Rad.=C
Rad.=D
90°
E=A, B=7/8 A, C=2A, D=3/8 A
Flat Head.
80°
B=1/4 A, C=3/32 A, D=2A
(F=9/16 A approximately)
E=A, B=1 1/2 A+1/8
F=3/4 A+1/16
G=3/4 A
E=A, B=1 1/2 A+1/8
C=2A, F=3/4 A+1/16
G=3/4 A
Finish for Ends of Machine Screws.
Finish for Ends of Bolts, Cap Screws and Studs
Cap Screw Head.
Round Head.
Fillister Head
E=A, C=2A
Distance across Flat=B
B={A+3/16" until A exceeds 1/2"
A+1/4" when A exceeds 1/2"
E=3/4 A, B=1/4 A,
C=1/2 A, D=1 3/4 A
E=3/4 A, B=1/4 A,
C=1/2 A, D=1 1/2 A.

Fig. 32

70. Fig. **13** is a hexagon-head capscrew, shown in perspective in Fig. 30 (*c*). The head of the capscrew is smaller than a corresponding hexagon-head bolt, being $1\frac{1}{4}$ inches across flats. The dimensions given will be followed, and are standard dimensions for a bolt of this size. The curve of the head is drawn by taking radius 2 times diameter of the bolt.

Fig. **14** represents a $\frac{1}{2}$-inch 13-thread setscrew, $1\frac{3}{8}$ inches long. Head is $\frac{1}{2}$ inch across flats, and the two curves on it are struck with a radius equal to twice the diameter of the screw. Draw the curves at the neck of the screw with a radius of $\frac{1}{8}$ inch. The information needed for drawing the lower end is given in Fig. 32.

The form of setscrew shown in Fig. **14** is the one most in use. Some other forms are represented in Fig. 33; that in (*a*) is called



(*a*) (*b*) FIG. 33 (*c*) (*d*)

a *cone-point setscrew*, in (*b*) a *cupped setscrew*, in (*c*) a *round, pivot-point setscrew*, and in (*d*) a *headless, cone-point setscrew*.

When the diameter of a screw is small and the number of threads per inch great no attempt should be made to draw in the actual number of threads. In such cases they should be drawn so as to make a good appearance.

71. Fig. **15** represents a round-head, 14–24 machine screw, $1\frac{3}{4}$ inches long; 14 is the gauge of the body of the screw; 24 gives the number of threads per inch. The screw is drawn by drawing a center line and laying off the parts as shown. No. 14 gauge practically corresponds to $\frac{1}{4}$ inch, and measurements may be made with this as a basis; thickness of the head is $\frac{3}{16}$ inch; width of head is $\frac{7}{16}$ inch.

The outline of the head should be a compound curve, but on account of the small size of the view it is difficult to show it

in this form; it will suffice if in its place a circular arc is drawn with a radius of $\frac{7}{32}$ inch. Figs. **15**, **17**, and **22** are illustrated in Fig. 34.

72. Fig. **16** is a fillister-head machine screw of the same dimensions as that shown in Fig. **15**. The head is $\frac{3}{16}$ inch thick below the round top and $\frac{3}{8}$ inch in diameter. The radius of the round top is equal to the diameter of head.

73. Fig. **17** is a machine screw with length and diameter corresponding to those in Figs. **15** and **16**, except that it has a flat head; thickness of head is $\frac{9}{64}$ inch; diameter of head, $\frac{15}{32}$ inch.

It will be noticed that the dimensions for length of screws are given under the head in Figs. **15** and **16**, and including head in Fig. **17**.

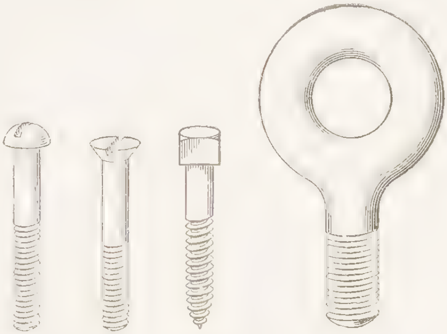


Fig. 34

74. Fig. **18** represents a cotter pin 1 inch long and $\frac{1}{8}$ inch in diameter. This pin is split and is put through the ends of bolts or studs to prevent nuts or washers working off. Make the eye $\frac{1}{4}$ inch in diameter.

75. Figs. **19** and **20** are conventional methods of representing round-head and flat-head wood screws. Dimensions previously given apply to these screws, except the gauge of body is No. 12, which approximately corresponds to $\frac{7}{32}$ inch. Diameters of heads of Figs. **19** and **20** are approximately $\frac{7}{16}$ inch and $\frac{3}{8}$ inch, respectively. Make the straight parts of the screws $\frac{5}{8}$ inch long, and the rounded points $\frac{1}{16}$ inch thick.

76. Fig. **21** shows a 2-inch eyebolt, $4\frac{1}{2}$ threads to the inch, with a 3-inch hole in the eye and corresponding dimensions outside.

This detail is illustrated in perspective in Fig. 34, and Fig. 35 shows the construction of the curved portion where the bolt proper joins the eye.

77. Fig. 22 is the representation of a $\frac{1}{4}$-inch lagscrew, $1\frac{5}{8}$ inches long. It is shown in perspective in Fig. 34. Lagscrews have square heads. The head is $\frac{3}{8}$ inch across flats and the curve is drawn with a radius of $\frac{1}{2}$ inch. The body of the bolt is drawn similar to Fig. 19.

78. Figs. 23 and 24 give conventional methods of representing keys drawn to one-half size or to a scale of 6 inches = 1 foot; they are plainly dimensioned and will need no detailed description of method of drawing them. These figures also indicate a convention quite frequently employed to show a section in a view itself instead of drawing a separate sectional view. The little squares indicate the depth of the keys and the shape of a cross-section.

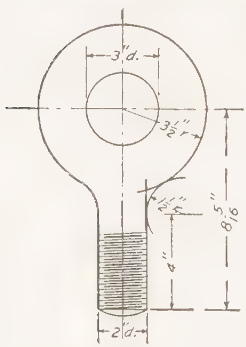


Fig. 35

79. Parts represented in Figs. 9 to 24 are standard parts, which are seldom, if ever, drawn on detailed drawings. They are, however, included in the list of materials, and they are frequently shown in assembly drawings, in which case they will be drawn as represented, and with the principal dimensions only, if any, given.

Additional information on the construction of standard nuts and bolts, machine and wood screws, together with the standard gauges for Morse drills, and steam, gas, and water pipes are found in the following Useful Tables.

USEFUL TABLES

80. Forms of Bolt Heads, Nuts, and Screw Heads. The information required for the construction of the standard forms of bolt heads, nuts, and the principal screw heads is given in Fig. 32. The several dimensions are indicated by capital letters in the diagrams and the relations between these dimensions

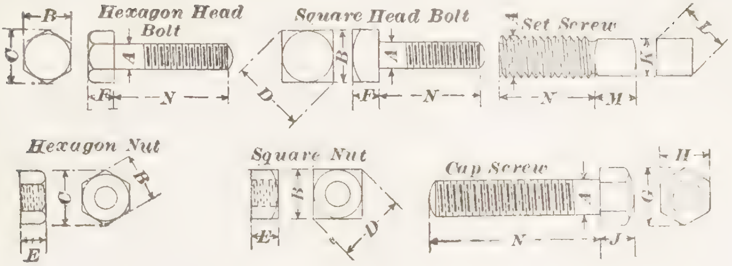


TABLE I

DIMENSIONS OF STANDARD-FINISHED BOLTS, NUTS, SET, AND CAP SCREWS

A	Threads Per Inch	Bolt Dimensions					Cap-Screw Dimensions			Setscrew Dimensions		
		B	C	D	E	F	G	H	J	K	L	M
$\frac{1}{4}$	20	$\frac{1}{2}$	$\frac{37}{64}$	$\frac{45}{64}$	$\frac{1}{4}$	$\frac{1}{4}$				$\frac{1}{4}$	$\frac{23}{64}$	$\frac{1}{4}$
$\frac{5}{16}$	18	$\frac{19}{32}$	$\frac{11}{16}$	$\frac{27}{32}$	$\frac{5}{16}$	$\frac{19}{64}$	$\frac{37}{64}$	$\frac{1}{2}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{7}{16}$	$\frac{5}{16}$
$\frac{3}{8}$	16	$\frac{11}{16}$	$\frac{51}{64}$	$\frac{31}{32}$	$\frac{3}{8}$	$\frac{11}{32}$	$\frac{21}{32}$	$\frac{9}{16}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{17}{32}$	$\frac{3}{8}$
$\frac{7}{16}$	14	$\frac{25}{32}$	$\frac{29}{32}$	$1\frac{7}{64}$	$\frac{7}{16}$	$\frac{25}{64}$						
$\frac{1}{2}$	13	$\frac{7}{8}$	$1\frac{1}{64}$	$1\frac{15}{64}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{45}{64}$	$\frac{1}{2}$
$\frac{5}{8}$	11	$1\frac{1}{16}$	$1\frac{15}{64}$	$1\frac{1}{2}$	$\frac{5}{8}$	$\frac{17}{32}$	1	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{7}{8}$	$\frac{5}{8}$
$\frac{3}{4}$	10	$1\frac{1}{4}$	$1\frac{7}{16}$	$1\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$1\frac{5}{32}$	1	$\frac{3}{4}$	$\frac{3}{4}$	$1\frac{1}{16}$	$\frac{3}{4}$
$\frac{7}{8}$	9	$1\frac{7}{16}$	$1\frac{21}{32}$	$2\frac{1}{32}$	$\frac{7}{8}$	$\frac{23}{32}$	$1\frac{5}{16}$	$1\frac{1}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$1\frac{15}{64}$	$\frac{7}{8}$
1	8	$1\frac{5}{8}$	$1\frac{7}{8}$	$2\frac{19}{64}$	1	$\frac{13}{16}$	$1\frac{7}{16}$	$1\frac{1}{4}$	1	1	$1\frac{13}{32}$	1
$1\frac{1}{8}$	7	$1\frac{13}{16}$	$1\frac{15}{16}$	$2\frac{9}{16}$	$1\frac{1}{8}$	$\frac{29}{32}$						
$1\frac{1}{4}$	7	2	$2\frac{5}{16}$	$2\frac{53}{64}$	$1\frac{1}{4}$	1	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$			
$1\frac{1}{2}$	6	$2\frac{3}{8}$	$2\frac{3}{4}$	$3\frac{23}{64}$	$1\frac{1}{2}$	$1\frac{3}{16}$						
$1\frac{3}{4}$	5	$2\frac{3}{4}$	$3\frac{11}{64}$	$3\frac{57}{64}$	$1\frac{3}{4}$	$1\frac{3}{8}$						
2	$4\frac{1}{2}$	$3\frac{1}{8}$	$3\frac{39}{64}$	$4\frac{27}{64}$	2	$1\frac{9}{16}$						
$2\frac{1}{4}$	$4\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{3}{64}$	$4\frac{61}{64}$	$2\frac{1}{4}$	$1\frac{3}{4}$						
$2\frac{1}{2}$	4	$3\frac{7}{8}$	$4\frac{15}{16}$	$5\frac{31}{64}$	$2\frac{1}{2}$	$1\frac{15}{16}$						
$2\frac{3}{4}$	4	$4\frac{1}{4}$	$4\frac{29}{32}$	$6\frac{1}{64}$	$2\frac{3}{4}$	$2\frac{1}{8}$						
3	$3\frac{1}{2}$	$4\frac{5}{8}$	$5\frac{11}{32}$	$6\frac{35}{64}$	3	$2\frac{5}{16}$						
$3\frac{1}{4}$	$3\frac{1}{2}$	5	$5\frac{25}{32}$	$7\frac{5}{64}$	$3\frac{1}{4}$	$2\frac{1}{2}$						
$3\frac{1}{2}$	$3\frac{1}{4}$	$5\frac{3}{8}$	$6\frac{13}{64}$	$7\frac{19}{32}$	$3\frac{1}{2}$	$2\frac{11}{16}$						
$3\frac{3}{4}$	3	$5\frac{3}{4}$	$6\frac{41}{64}$	$8\frac{1}{8}$	$3\frac{3}{4}$	$2\frac{7}{8}$						
4	3	$6\frac{1}{8}$	$7\frac{5}{64}$	$8\frac{21}{32}$	4	$3\frac{1}{16}$						
$4\frac{1}{4}$	$2\frac{7}{8}$	$6\frac{1}{2}$	$7\frac{1}{2}$	$9\frac{3}{16}$	$4\frac{1}{4}$	$3\frac{1}{4}$						
$4\frac{1}{2}$	$2\frac{3}{4}$	$6\frac{7}{8}$	$7\frac{15}{16}$	$9\frac{23}{32}$	$4\frac{1}{2}$	$3\frac{7}{16}$						
$4\frac{3}{4}$	$2\frac{5}{8}$	$7\frac{1}{4}$	$8\frac{3}{8}$	$10\frac{1}{4}$	$4\frac{3}{4}$	$3\frac{5}{8}$						
5	$2\frac{1}{2}$	$7\frac{5}{8}$	$8\frac{13}{16}$	$10\frac{25}{32}$	5	$3\frac{13}{16}$						

TABLE II

STANDARD MACHINE AND WOOD SCREWS

Gauge No.	Diameter Inches	Threads Per Inch	Diameter of Round Head	Diameter of Filister Head	Diameter of Flat Head
000	.0315				
00	.0447				
0	.0578				
1	.0710				
2	.0842	64	.1544	.1332	.1631
3	.0973	48	.1786	.1545	.1894
4	.1105	36	.2028	.1747	.2158
5	.1236	32	.2270	.1985	.2421
6	.1368	32	.2510	.2175	.2684
7	.1500	32	.2754	.2392	.2947
8	.1631	32	.2936	.2610	.3210
9	.1763	32	.3238	.2805	.3474
10	.1894	32	.3480	.3035	.3737
11	.2026	24			
12	.2158	24	.3922	.3445	.4263
13	.2289	22			
14	.2421	20	.4364	.3885	.4790
15	.2552	20			
16	.2684	18	.4866	.4300	.5316
17	.2816	18			
18	.2947	18	.5248	.4710	.5842
19	.3079	18			
20	.3210	16	.5690	.5200	.6308
21	.3342				
22	.3474	16	.6106	.5557	.6894
23	.3605				
24	.3737	16	.6522	.6005	.7420

TABLE III

MORSE TWIST-DRILL AND STEEL-WIRE GAUGE

Gauge No.	Diameter Inch	Gauge No.	Diameter Inch	Gauge No.	Diameter Inch
1	.2280	33	.1130	65	.0350
2	.2210	34	.1110	66	.0330
3	.2130	35	.1100	67	.0320
4	.2090	36	.1065	68	.0310
5	.2055	37	.1040	69	.02925
6	.2040	38	.1015	70	.0280
7	.2010	39	.0995	71	.0260
8	.1990	40	.0980	72	.0250
9	.1960	41	.0960	73	.0240
10	.1935	42	.0935	74	.0225
11	.1910	43	.0890	75	.0210
12	.1890	44	.0860	76	.0200
13	.1850	45	.0820	77	.0180
14	.1820	46	.0810	78	.0160
15	.1800	47	.0785	79	.0145
16	.1770	48	.0760	80	.0135
17	.1730	49	.0730		
18	.1695	50	.0700		
19	.1660	51	.0670		
20	.1610	52	.0635		
21	.1590	53	.0595		
22	.1570	54	.0550		
23	.1540	55	.0520		
24	.1520	56	.0465		
25	.1495	57	.0430		
26	.1470	58	.0420		
27	.1440	59	.0410		
28	.1405	60	.0400		
29	.1360	61	.0390		
30	.1285	62	.0380		
31	.1200	63	.0370		
32	.1160	64	.0360		

TABLE IV

U. S. STANDARD STEAM, GAS, AND WATER PIPE

Sizes of Pipes Inches	Threads per Inch	Actual External Diameter Inches	Actual Internal Diameter Inches	Total Length of Thread	Length of Perfect Thread	Size of Hole for Tap	Diameter of Thread at End of Pipe	
							Outside	At Bottom of Thread
$\frac{1}{8}$	27	.405	.270	.41	.19	$\frac{11}{32}$	.393	.334
$\frac{1}{4}$	18	.540	.364	.62	.29	$\frac{7}{16}$	.522	.433
$\frac{3}{8}$	18	.675	.494	.63	.30	$\frac{37}{64}$	.658	.568
$\frac{1}{2}$	14	.840	.623	.83	.39	$\frac{23}{32}$	.815	.701
$\frac{3}{4}$	14	1.050	.824	.84	.40	$\frac{59}{64}$	1.025	.911
1	$11\frac{1}{2}$	1.315	1.048	1.03	.51	$1\frac{5}{32}$	1.283	1.144
$1\frac{1}{4}$	$11\frac{1}{2}$	1.660	1.380	1.06	.54	$1\frac{1}{2}$	1.627	1.488
$1\frac{1}{2}$	$11\frac{1}{2}$	1.900	1.611	1.07	.55	$1\frac{47}{64}$	1.866	1.727
2	$11\frac{1}{2}$	2.375	2.067	1.10	.58	$2\frac{13}{64}$	2.339	2.223
$2\frac{1}{2}$	8	2.875	2.468	1.64	.89	$2\frac{5}{8}$	2.820	2.620
3	8	3.500	3.067	1.70	.95	$3\frac{1}{4}$	3.441	3.241
$3\frac{1}{2}$	8	4.000	3.548	1.75	1.00	$3\frac{3}{4}$	3.938	3.738
4	8	4.500	4.026	1.80	1.05	$4\frac{1}{4}$	4.434	4.234
$4\frac{1}{2}$	8	5.000	4.508	1.85	1.10	$4\frac{3}{4}$	4.931	4.731
5	8	5.563	5.045	1.91	1.16	$5\frac{19}{64}$	5.490	5.290
6	8	6.625	6.065	2.01	1.26	$6\frac{23}{64}$	6.546	6.346
7	8	7.625	7.023	2.11	1.36	$7\frac{11}{32}$	7.540	7.340
8	8	8.625	7.982	2.21	1.46	$8\frac{11}{32}$	8.534	8.334
9	8	9.625	8.937	2.32	1.57	$9\frac{11}{32}$	9.527	9.327
10	8	10.750	10.019	2.43	1.68	$10\frac{29}{64}$	10.645	10.445

NOTE.—The taper of the threaded part is 1 in 16.

are stated either below each separate diagram or below each series of diagrams. It is seen that these dimensions are all based on the diameters of the bolts or screws.

81. In order to avoid the calculations required to use these diagrams, the standard dimensions of bolt heads, nuts, and screw heads have been given in Table I, for the sizes mostly in use. Dimensions, corresponding with those indicated by capital letters in the diagrams, are found in the table in columns headed by similar letters. For instance: It is required to find the height of a hexagon head for a bolt 1 inch in diameter. In the diagram of a hexagon head the letter *F* represents its height. To find its numerical value from the table, look along the column *A* until the diameter 1 is found; then in a horizontal direction to the column *F*, where the value $\frac{13}{16}$ is found, which is the dimension required.

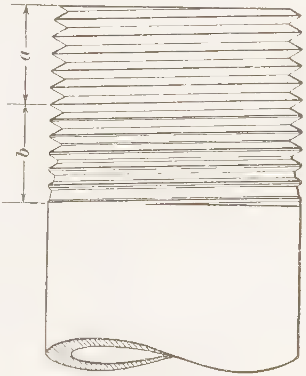


Fig. 36

82. Small standard machine or wood screws are indicated by gauge numbers instead of by diameters. Table II gives the gauge numbers and the corresponding diameters of the sizes mostly used. To draw a screw of a certain gauge, find its diameter in the table, and lay out the head according to the instructions given with the diagrams in Fig. 32.

83. Diameters of Small Holes.—The sizes of small holes are generally indicated by the gauge number of the drills used in drilling them instead of by their diameters. Table III gives the gauge numbers and corresponding diameters of the Morse twist drills. The table will also serve to indicate sizes represented by the gauge numbers of ordinary steel wire.

84. Pipe Threads.—The pitches and depths of the screw threads on pipes cannot be made according to the rules applying

to ordinary screw threads, as in that case the depth of the thread would be greater than the thickness of the pipe.

Table IV gives the standard dimensions of pipe threads. By means of the data given under the head of Total Length of Thread and Length of Perfect Thread, it is possible to determine the length of the part containing imperfect threads. It should be noted that the number of the latter is a constant for all diameters; that is, according to the standard adopted, there should always be six imperfect threads, two of which are imperfect only at top, and four both at top and bottom. The number of perfect threads will vary according to the diameter of the pipe or nipple.

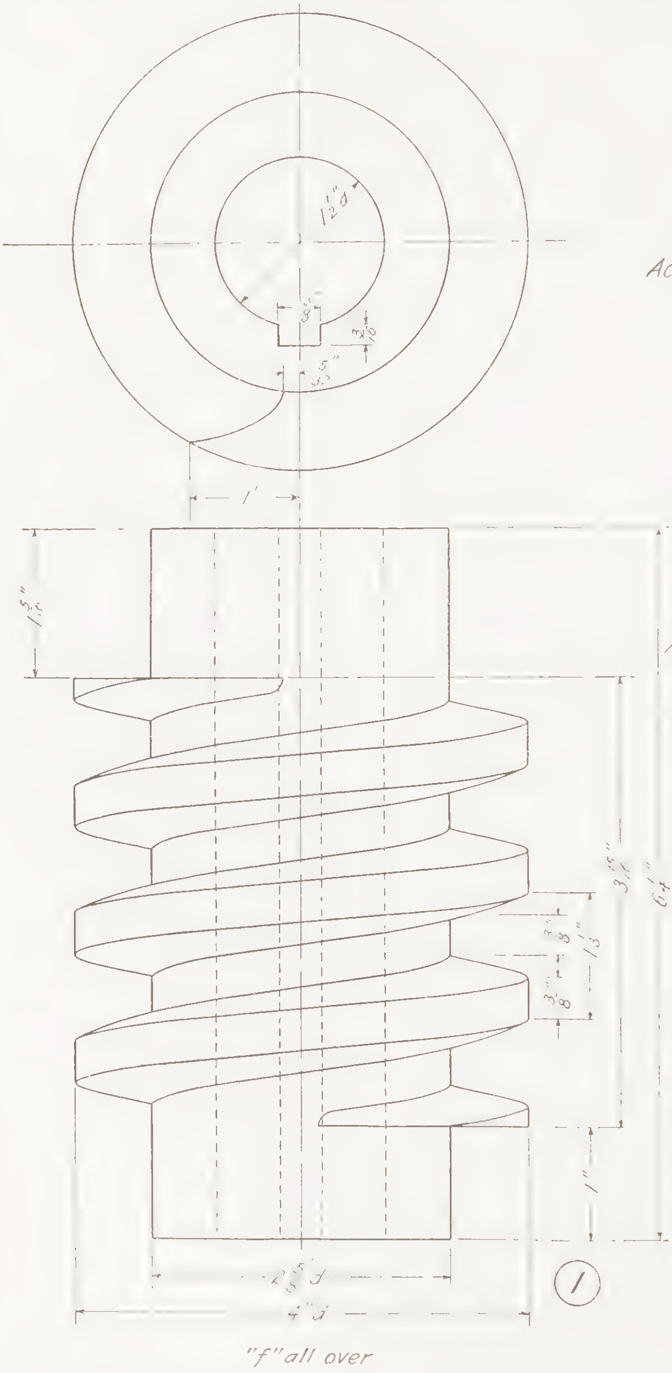
FIG. 37

The meaning of perfect and imperfect threads will be made clear by referring to Fig. 36, in which the part marked *a* represents the perfect threads, while the portion marked *b* shows the imperfect threads.

PLATE 1004, TITLE: HELICAL FORMS

85. Plate 1004 is intended to give practice in drawing helical curves. In the previous plates, screw threads have been represented by straight lines; and this conventional plan is followed whenever possible to save time. When, however, the dimensions of a threaded piece are large, especially when the lead of the thread is steep and the scale used is large, the true projection of the screw thread is often drawn; this the draftsman should do by the quickest method possible. The necessary directions are here given for each of the three parts represented on this plate.

To assist the beginner in forming a clear idea of the parts represented by the drawings, shaded views of the objects are



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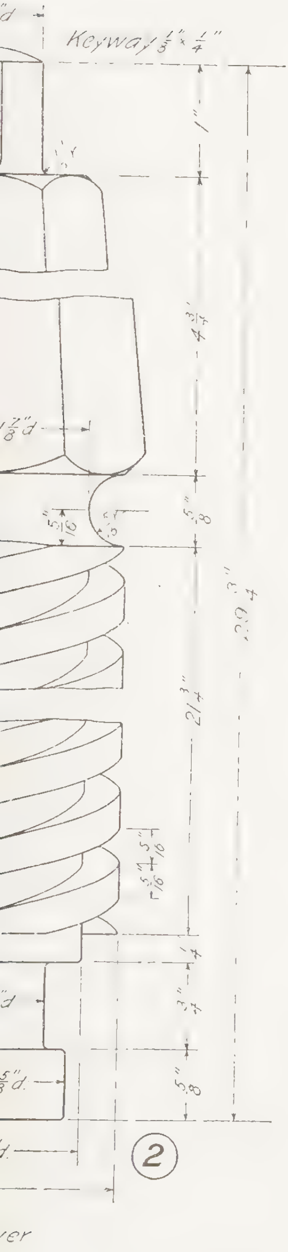
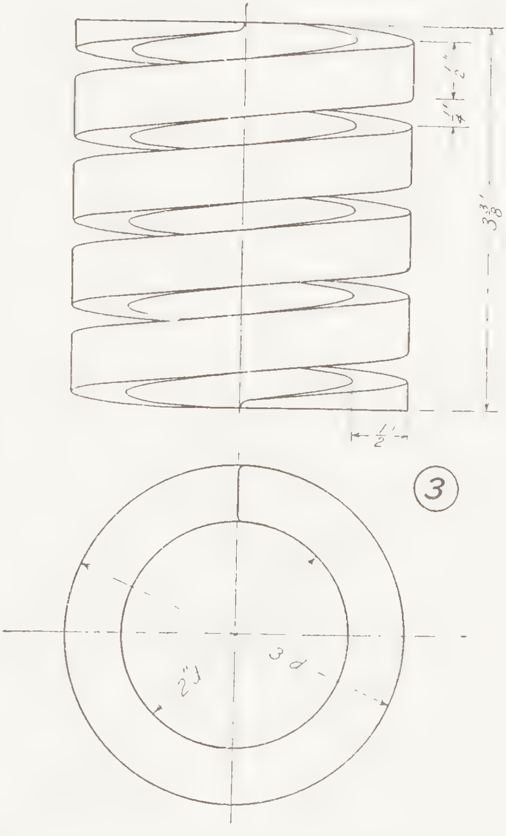




1	Spring	3	Spring Steel		
1	Adjusting Screw	2	Machine Steel		
1	Worm	1	Brass	Pattern	A

HELICAL FORMS

DRAWN BY ....
DATE ....

1004

Fig. 38

shown in Figs. 37, 38, and 39. Attention is particularly called to the method of drawing the adjusting screw, **2**, it being broken at two points, in order to permit it to be drawn within the limits of the plate.

86. Draw border lines and lines for the title as shown, allowing space above the title for the material list of the three parts that are to be described and drawn. All the parts shown on this plate are to be drawn full size.

Part **1**, shown in perspective in Fig. 37, is a single-thread worm with a $1\frac{1}{2}$-inch hole through it; its over-all length is $6\frac{1}{4}$ inches; the hub diameter is $2\frac{5}{8}$ inches, which is also the diameter of the worm at the bottom of the thread. The length of the threaded portion is $3\frac{15}{16}$ inches, the hub extending beyond the thread 1 inch at one end and $1\frac{5}{16}$ inches at the other end. The worm has a diameter of 4 inches over the outside of the threads.

The method of drawing the worm is described in connection with the illustration, Fig. 40. Draw a center line $m\,n$, $3\frac{1}{2}$ inches from the left-hand border line. Parallel to this line draw two other lines $p\,q$ and $r\,s$, each $2\frac{5}{8} \div 2 = 1\frac{5}{16}$ inches from it; these lines determine the bottom of the thread, and also the diameter of the hub. Then draw two lines $t\,u$ and $v\,w$ parallel to the center line, and $4 \div 2 = 2$ inches from it; they determine the top of the thread.

Locate two points a and a' on the center line $6\frac{1}{4}$ inches apart, a being $1\frac{3}{4}$ inches from the lower border line. Through both of these points draw with the T square a perpendicular to the center line, thus defining the length of the hub. Locate two other points b' and b on the center line, one $1\frac{5}{16}$ inches below a' and the other 1 inch above a. Through these points draw perpendiculars to $m\,n$; these lines are to limit the length of the threaded portion of the worm.

87. Now proceed to construct the thread. This will necessitate a number of construction lines being drawn that are not to appear on the final tracing; they are made on the pencil drawing only. The pitch, that is, the distance between the top of one turn of the thread and the corresponding point on the next turn, is $1\frac{1}{8}$ inches, and since the length of the threaded portion of the worm is $3\frac{15}{16}$ inches, there will be $3\frac{15}{16} \div 1\frac{1}{8} = 3\frac{1}{2}$ turns of the thread; hence, the number of equal spaces representing the tops and bottoms of the thread is $3\frac{1}{2} \times 2 = 7$; therefore, divide the line $b\,b'$ into seven equal parts $b\,I$, $I\,II$, etc. The thread itself is to have approximately the shape of a **V** thread, except that instead of making the angle x 60°, this angle is determined from the pitch of the thread and the amount of flattening at the top and bottom. On the plate, the dimensions show that the flattening at the top, and also at the bottom, is $\frac{3}{8}$ inch; that is, $d\,e$ and $f\,g$, Fig. 40, are each equal to $\frac{3}{8}$ inch. Hence, on each side of the division points b, I, II, III, etc., just obtained, lay off $\frac{3}{8} \div 2 = \frac{3}{16}$ inch, and draw $c\,c'$, $d\,d'$, $e\,e'$, $f\,f'$, $g\,g'$, etc., perpendicular to $m\,n$, which, intersecting with the lines $t\,u$, $p\,q$, $r\,s$, and $v\,w$, locate the points defining the tops and bottoms of the thread. Draw the straight lines $c\,d$, $e\,f$, etc., and $c'\,d'$, $e'\,f'$, etc., as shown. Note herewith that the top of the thread on one side corresponds to the bottom of the thread on the other side of the center line.

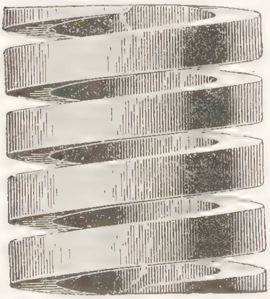


FIG. 39

88. To construct the curves defining the helixes, locate some point o on the center line (this point on the plate will be at a distance of $2\frac{1}{2}$ inches from the upper border line), and with o as a center, draw two semicircles whose diameters are equal to the top and the bottom diameters of the threads; that is, 4 inches and $2\frac{5}{8}$ inches, respectively. These semicircles constitute part of the plan view to be drawn on the plate. Divide the semicircles into any convenient number of equal parts. This is done by first dividing the exterior semicircle into the

required number of parts, as *0*, *1*, *2*, *3*, *4*, *5*, and *6*, then drawing radii to each point from *o*; this divides the interior semicircle into the same number of equal parts at the points *0′*, *1′*, *2′*,

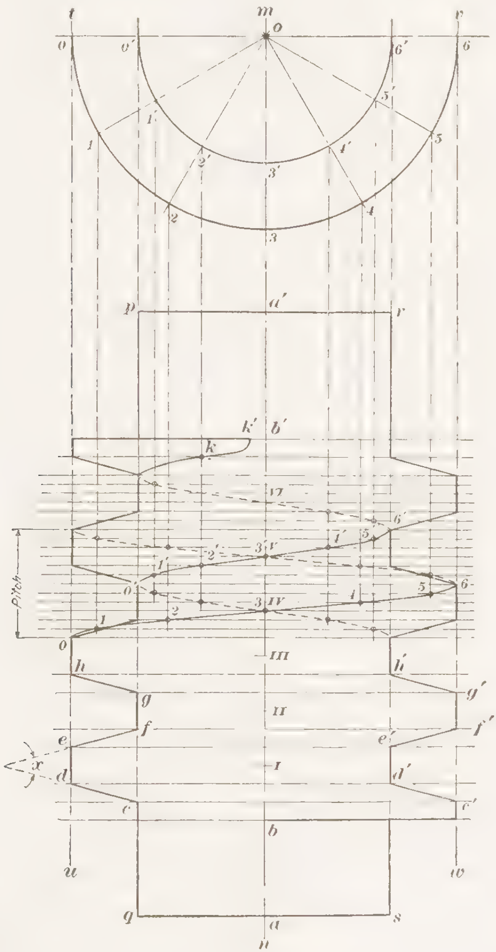


FIG. 40

3′, *4′*, *5′*, and *6′*. The division of the circles is most quickly effected by the use of the 60° triangle. If, as in this particular case, six divisions are chosen for reasons now to be explained,

the pitch must be divided into twice the number of equal parts that the semicircles have been divided into, that is, into 12 parts, in order to also delineate the rear part of the thread. As the pitch is $1\frac{1}{8}$ inches $= \frac{18}{16}$ inches, these divisions are $\frac{18}{16} \div 12 = \frac{3}{32}$ inch apart. The lines $c\,c'$, $d\,d'$, $e\,e'$, $f\,f'$, etc., are either $\frac{3}{16}$ inch or $\frac{3}{8}$ inch apart, and those that are $\frac{3}{8}$ inch apart already have the distance between them halved by the points *I*, *II*, *III*, etc.; hence, these divisions can be utilized at once, and it is only necessary to halve them again to get the required 12 divisions. Draw perpendiculars to $m\,n$ through the division points. From points *1*, *2*, *3*, *4*, *5*, and *1'*, *2'*, *3'*, *4'*, *5'*, of the semicircles, draw lines to intersect the aforesaid perpendiculars. The intersections are points of the helixes, those made with lines *1–1*, *2–2*, *3–3*, *4–4*, *5–5* belonging to the top of the thread, those made with lines *1'–1'*, *2'–2'*, *3'–3'*, *4'–4'*, *5'–5'* belonging to the bottom of the thread, as shown more plainly in Fig. 41. Through the points that have thus been located, draw

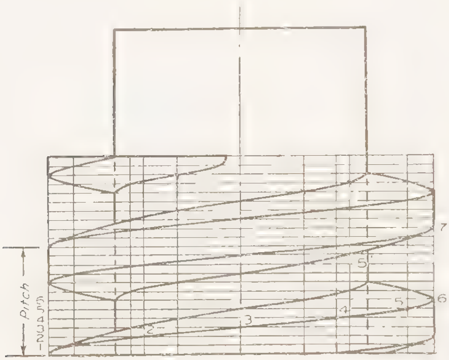


FIG. 41

a curve, as shown, using for this purpose the irregular curve. The outlines of the thread will then appear as shown in Fig. 41, which represents the upper part of the worm, with the construction lines and the complete front part of a thread drawn in.

It will be noticed that the part of the curves between the points *2* and *4*, and *2'* and *4'*, respectively, is very flat; it is so nearly a straight line that it may be so considered and drawn, and the irregular curve will have to be used only to draw the parts *0–1–2*, *0'–1'–2'*, *4–5–6*, and *4'–5'* of the helix. It will also be noted that the part of the curve marked *5'–6'* in Fig. 40 does not appear in the finished curve in Fig. 41. It becomes hidden by the under surface, which is bounded by a curved line continuing from *5'* to point *7*. It will be well to draw the

straight portions of the helixes first and, since these are parallel, they may be drawn by the use of two triangles, as described in *Geometrical Drawing*, Part 1, and then the curved portions may be joined on.

89. The part of the thread shown in Fig. 41 having been drawn, the remainder may be completed in the same manner. When a comparatively long screw is to be drawn, requiring the curves to be duplicated many times, a method of saving time and of securing uniformity in the appearance of the curves is first to lay out the curves for one complete turn of the thread, then to cut a curve, of the same shape as those already drawn, out of bristol board or cardboard and use it as a templet.

To complete the elevation as shown on the plate, draw two lines parallel to the center line and $1\frac{1}{2} \div 2 = \frac{3}{4}$ inch from it; these lines will be dotted and determine the location of the hole through the hub.

90. The top view of the worm is shown above the figure just constructed, and consists mainly of circles, the center one showing the hole, the next one the diameter of the hub, and the outer one the outside diameter of the screw. This view is located with its center on the extended center line of the lower view, with the center of the concentric circles $2\frac{1}{2}$ inches below the upper border line. When the thread is cut in the lathe, it runs out on both ends, naturally, into thin edges, as shown in Fig. 37, which are afterwards rounded off more bluntly. This is shown conventionally by the curves in the plan and elevation; see $k\ k'$, Fig. 40.

A keyway $\frac{3}{16}$ inch deep and $\frac{3}{8}$ inch wide is cut through the central part of the worm in order to keep it from turning on the shaft on which it will be placed. This keyway is plainly shown in the plan, and is indicated in the elevation by dotted lines.

91. Part 2 on Plate 1004 is a triple-thread adjusting screw with a tapered hexagonal head, as shown in perspective in Fig. 38, and is to be drawn full size. It is also to be shown broken at two points, since if shown in its full length, a smaller scale would be necessary.

Draw a center line parallel to and 9 inches from the left-hand border line. The method of constructing the screw is shown in Fig. 42 and is the same as that shown in connection with the worm, except that the thread is square instead of **V**-shaped. The lead or distance between corresponding points of the same thread is $1\frac{7}{8}$ inches; the depth of the thread is $\frac{5}{16}$ inch, and the width of the thread at the base is $\frac{5}{16}$ inch. Three separate curves are constructed, there being three separate threads. A templet can be made as before, after one of the threads has been fully constructed.

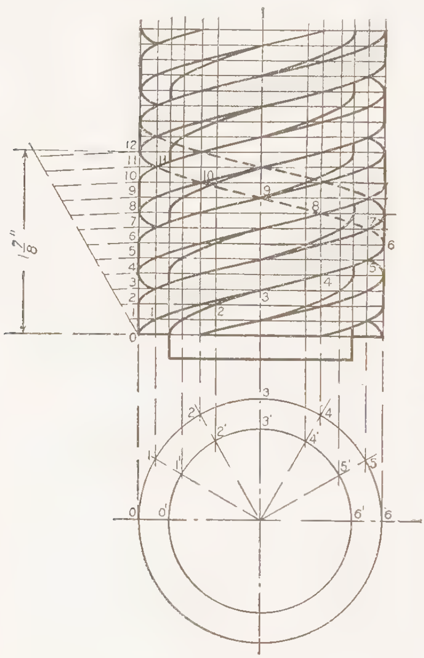


Fig. 42

In order properly to construct the tapered hexagonal head, it should be noticed (see Plate 1004) that the dimension given is $1\frac{3}{4}$ inches across flats at a point 1 inch below the upper end of the adjusting screw, the rounded top portion not being considered in dimensioning. Locate the point o on the center line, Fig. 43, 3 inches below the upper border line, and draw through it a perpendicular $a\,g$. At a distance of $4\frac{3}{4}$ inches below this line, draw another line $b\,h$. Above and below these lines, which mark the small and the large ends of the hexagonal head, locate at convenient distances the horizontal center lines $x\,y$ and $x'\,y'$. By the aid of the 60° triangle construct the two regular hexagons dimensioned, respectively, $1\frac{3}{4}$ inches and $2\frac{1}{2}$ inches across flats. From the hexagon representing the small end of the tapered head, project the points a, c, e, and g, and from the

hexagon representing the large end project the points b, d, f, and h. Draw lines connecting the points $a\,b$, $c\,d$, $e\,f$, and $g\,h$. After these lines have been obtained and the curved edge lines at both ends have been drawn, the true shape of the head has been constructed. In order to have it come within the space given for it on the drawing plate, it will now be necessary to raise the lower part of the head. This is done by breaking, that is, removing, a part of the head and indicating the break by two freehand lines. In raising the lower part, place the line $b'\,h'$ $2\frac{5}{8}$ inches from line $a\,g$ and draw in the edge lines for the lower portion of the head, as shown in Fig. 43. The line $a'\,b'$ is drawn parallel with $a\,b$, $c'\,d'$ is drawn parallel to $c\,d$, $e'\,f'$ with $e\,f$, and $g'\,h'$ with $g\,h$. The other dimensions necessary for completing the drawing of the adjusting screw are found on the plate.

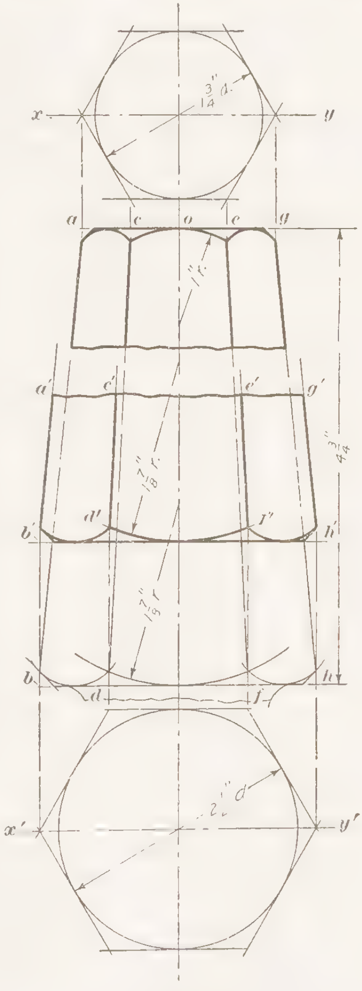


Fig. 43

92. Part 3 on Plate 1004 is a helical spring, drawn full size. This is also shown in perspective in Fig. 39. The spring is made of $\frac{1}{2}$-inch square steel wound around a 2-inch mandrel in such a manner that $\frac{1}{4}$-inch space remains between the turns for the play of the spring. The curves formed by the edges of the twisted steel bar are helixes, as in a screw thread,

and have a pitch equal to the width of the bar plus the clearance, or $\frac{1}{2}+\frac{1}{4}=\frac{3}{4}$ inch. The vertical center line of this detail should be located 3 inches from the right-hand border line and the horizontal center line of the bottom view, $4\frac{1}{2}$ inches above the lower border line. To draw the spring, proceed in a manner similar to that employed in drawing the worm, laying out, Fig. 44, the top and bottom lines, $g\,h$, $k\,l$, $o\,p$, etc., of the coil, the distance $h\,l$ being $\frac{1}{2}$ inch, $l\,p$ being $\frac{1}{4}$ inch, $p\,r$ being $\frac{1}{2}$ inch, etc., and then constructing the helixes. The latter are very flat, and it will be sufficient to determine just one point of the curves on each side near the extreme right and left, the rest being indicated by straight lines. To determine these points, draw in the plan, by use of a 30° triangle, two radii $o\,a$ and $o\,b$, as in Fig. 44; then, parallel with $m\,n$, from the points of intersection of the radii with the circles draw parallels $a\,a'$, $c\,c'$, $d\,d'$, and $b\,b'$. Since the angles $a\,o\,s$ and $b\,o\,s'$ are $30° = \frac{30}{360} = \frac{1}{12}$ of a circle, the pitch would be divided into 12 equal parts, were the helixes drawn exactly correct. Hence, on each side of the top and bottom lines of the coil lay off points e', e'', f', f'', etc., the distances $e\,e'$, $e\,e''$, etc., being $\frac{1}{12}$ of the pitch, or in this case, $\frac{3}{4} \div 12 = \frac{1}{16}$ inch. Draw the curves $e'\,g\,e''$, $f'\,g'\,f''$, etc. freehand, making them look uniform in outline. Do the same on the right-hand extremities of the helixes and connect the proper curves by straight lines, as shown. All the coils should be drawn in exactly the same manner.

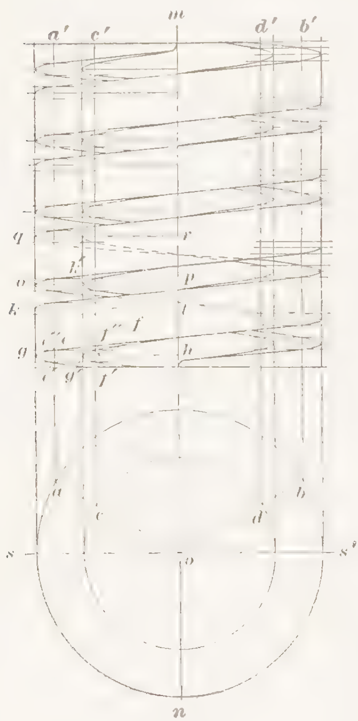
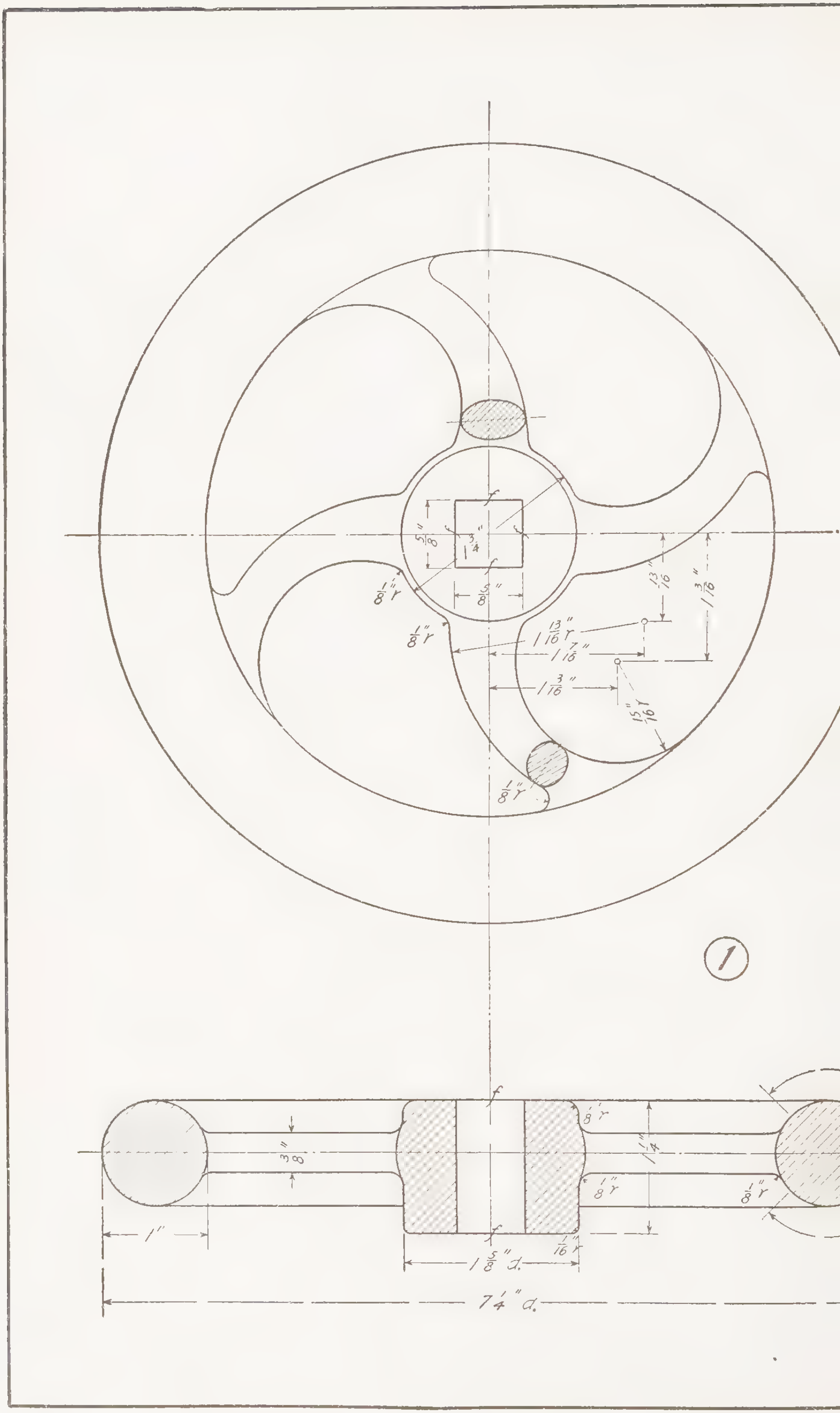


FIG. 44



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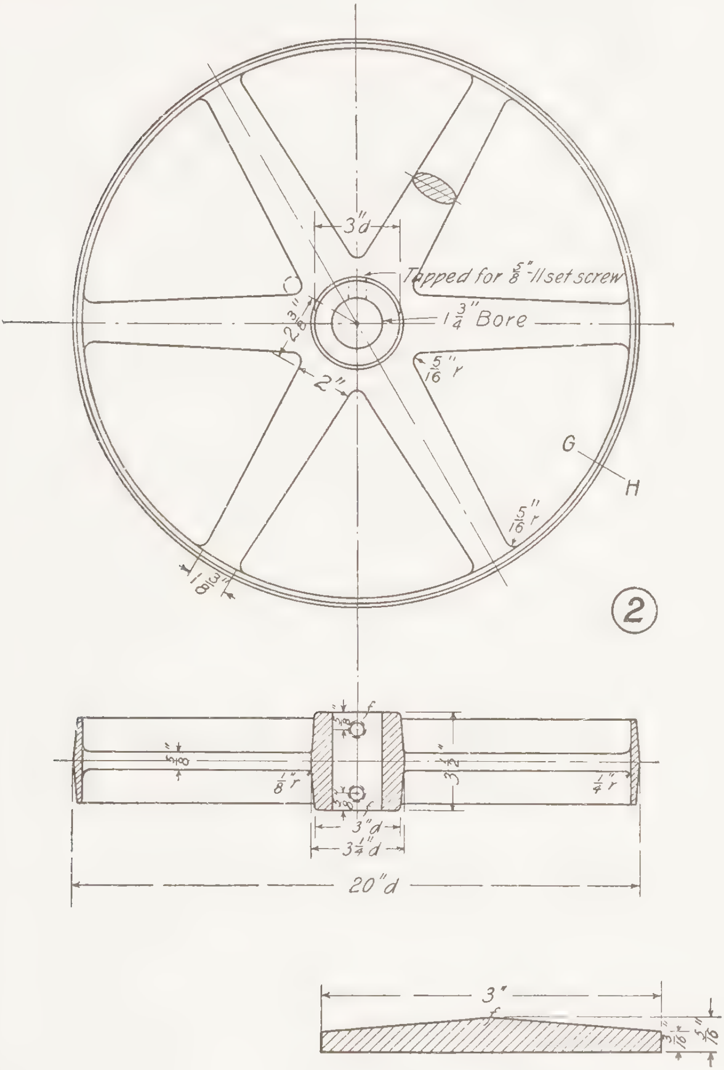

Section on line G.H.

2	5/8"-11 Set screws 7/8" long for part 2	3	Machine steel		
1	Pulley	2	Cast iron	999 E	
1	Hand wheel	1	Cast iron	Pattern	A

HAND WHEEL AND PULLEY

DRAWN BY ....

DATE ....

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93. When sending in the tracing of Plate 1004 for correction, the pencil drawing showing the helical constructions should be enclosed with the tracing.

PLATE 1005, TITLE: HAND WHEEL AND PULLEY

94. The objects to be drawn on Plate 1005 are illustrated in perspective in Figs. 45 and 46; on the drawing plate each object is represented by a plan and a sectional view. The relative sizes of the views of the hand wheel, Part 1, and the pulley, Part 2, should be noted. According to the dimensions given on the plate, the pulley is much larger than the wheel, but it appears smaller in the drawing, being drawn one-fourth size, or to a scale of 3 inches = 1 foot, while the hand wheel is drawn full size.

Fig. 45

It will be noted that, on account of the reduced scale to which the pulley was drawn, it was necessary to show full size a section on *G H* of the rim of the pulley, a method that is often used when, in cases like this, only a small part of the object requires a large scale.

A section or enlarged portion of this sort is usually placed as near as possible to the main view of the same part and is properly marked.

It will also be noticed that a third part, called for in the list of materials, is not shown on the drawing; this is a setscrew $\frac{5}{8}$ inch in diameter, 11 threads to the inch, a common and commercial article that is fully understood from the description given, thus: *$\frac{5}{8}''$–11 setscrew $\frac{7}{8}''$ long for Part 2.*

Finish marks are also used to a greater extent on this plate than on previous ones; some surfaces are to be finished while others are not. The main part of the rim of the hand wheel should be finished for the sake of appearance as well as for easier handling. On the inside of the rim, which is not so much visible, and where finishing would be difficult, it has been omitted. The ends of the hub have been finished for

alinement, as also have the four sides of the hole in order that it may fit better on the shaft. The hub of the pulley has been finished on the ends, for the same reason as the hub of the hand wheel. The hole in the pulley is bored to a certain dimension, therefore no finish has been marked. The circumference of the rim is finished to give a true surface for the belt, and the sides of the rim are also finished for the sake of appearance.

Another feature of this plate is the method of showing the forms of the arms of the hand wheel and pulley by sections on

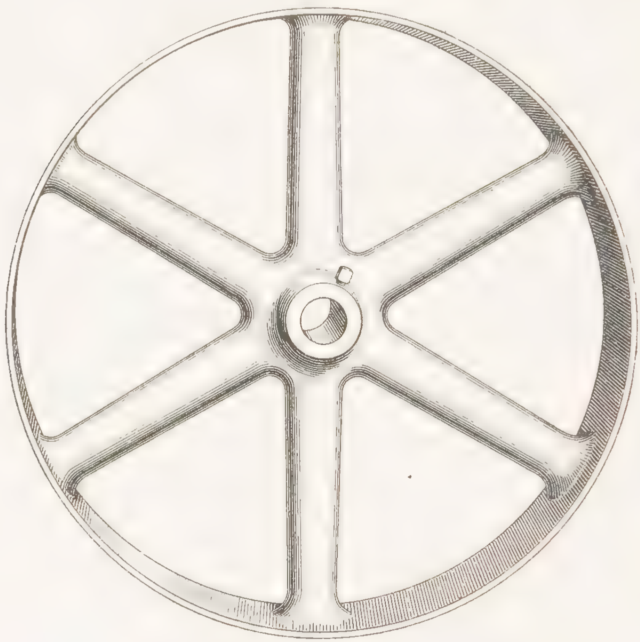


Fig. 46

the plans; it will be noted that the exact forms of these arms cannot be found from the two main views without these sections. Such sections are usually located on center lines marking the exact point where the section is taken. On the plan (top view) of Parts 1 and 2, cross-sections of the arms are shown at points near the hub and the rim in the hand wheel and midway between the hub and the rim in the pulley; these sections show that the

arms are oval in shape, the thicknesses being given in the lower views—$\frac{3}{8}$ inch in the hand wheel and $\frac{5}{8}$ inch in the pulley.

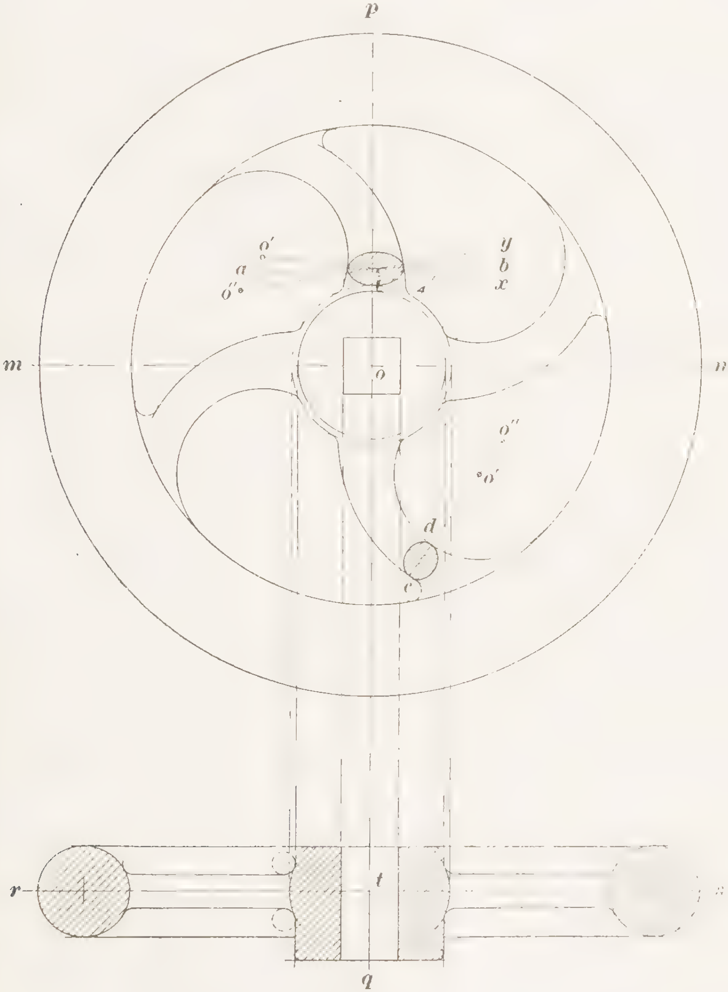


FIG. 47

95. To draw the plate proceed as follows: Beginning with Part **1**, draw a horizontal center line *m n*, Fig. 47, 5 inches from the upper border line, and a vertical center line *p q*,

$4\frac{1}{2}$ inches from the left-hand border line. With the point *o* of the intersection of these two center lines as a center, draw a circle $1\frac{5}{8}$ inches in diameter, showing the end view of the hub, next draw a circle $1\frac{3}{4}$ inches in diameter; this indicates the enlarged portion of the hub where the arms join it. Next draw a square with $\frac{5}{8}$-inch sides, whose center corresponds with the center of the hub; this indicates the end view of the hole that is put through the hub. Draw the external outline of the hand wheel, which is a circle $7\frac{1}{4}$ inches in diameter, and then the internal outline, a circle $5\frac{1}{4}$ inches in diameter. Then draw the arms, which are made up of circular arcs whose centers are located by giving their distances from the center lines. Leave the plan for the present and proceed to draw the lower view, which is a section taken on the center line *m n*.

The lower view is what is called a *conventional section*, and the sectioning indicates that the material is cast iron; this is verified by reference to the bill of materials. The rim is cut on the horizontal center line, and so is the square hole in the hub, but the hub itself is represented as being cut on a line passing between and free of the arms. This is done to avoid drawing the curves that would result in cutting the arms by a true central section, which would entail useless labor. Moreover, the conventional section allows the round outline of the hub to be shown at its enlarged central portion between the arms.

Draw a horizontal center line *r s*, Fig. 47, $2\frac{3}{8}$ inches from the bottom border line. On this center line lay off to the right and left of the point of intersection *t* with the vertical center line *p q* $(7\frac{1}{4}'' \div 2) - (1'' \div 2) = 3\frac{1}{8}$ inches, locating the centers of the circles representing the sections of the rim. Draw horizontal lines tangent to the 1-inch circles; lay off from the upper line $1\frac{1}{4}$ inches downwards, the length of the hub, and draw the bottom line of the hub. From the upper view or plan carry down vertical projection lines representing the square hole; also draw similar lines tangent to the circles representing the hub. Next lay off $\frac{3}{8}'' \div 2 = \frac{3}{16}$ inch each side of the center line *r s*, and draw the horizontal lines, indicating the thickness of the arms.

96. Round Corners and Fillets.—The curves representing the enlarged portion of hub in the lower figure, and the various small circular arcs rounding off the corners will now be drawn by using the radii given on the plate. Sharp corners are always avoided in machinery, especially in castings, unless called for by special reasons. Corners are, therefore, rounded off. In the case of concave corners the patternmaker often resorts to the use of some plastic material, such as putty, strips of leather, or even lead to fill in the corner so as to round it. From this practice the rounding out of a concave corner is called a **fillet**, and this term has come to be applied to the little circular arc used by the draftsman to represent it.

97. Next draw the rounded outlines of the enlarged portion of the hub. Lines drawn tangent from the circles representing the hub in the plan have already been projected to the sectional elevation, and the rounded edges and fillets are now to be drawn. The radius for the rounded outline of the enlarged portion of the hub has not been given and should be determined by trial; the centers will be located at some point on the center line $r s$.

Lastly, draw the cross-sections of the arms in the upper figure. As has been stated, the arms are elliptical or oval in section. They are so, however, only the greater part of their length; at their ends they are smoothly joined to the rim and the hub respectively, the ovals thus gradually flaring out to run over into the surfaces of the rim and hub. This joining need not be shown further than indicated by the fillets; the patternmaker will know how to proceed. The cross-sections are taken in the portion of the arm where they are sure to be truly oval.

The section in the lower part of the figure is taken on a line $c d$ (see Fig. 47) passing through the centers o' and o'' of both arcs outlining the shape of the arms. The cutting plane is thus perpendicular to both these curved outlines. The other section in the upper part of the figure near the hub is taken $\frac{1}{4}$ inch from the hub (where it is sure to be truly oval). This section cannot be perpendicular to both outlining circles, as

the cutting-plane line cannot be made to pass through both centers. Therefore, a cutting plane $a\,b$ is chosen midway between a plane $o'\,x$ passing through center o' and a plane $o''\,y$ passing through the center o''.

When drawing ovals of such small size it is not necessary, or in many cases possible, to construct them by the methods

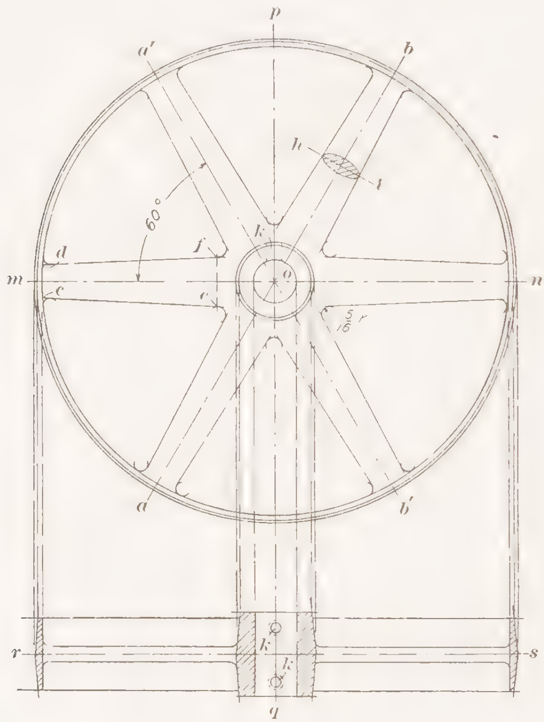


FIG. 48

given in *Geometrical Drawing*. With the four points, marking the length and the width of an oval, given, the elliptical curve can easily be drawn by means of the bow-pen and the irregular-curve ruler.

It will be noticed that for some circles the radii are given, and for others the diameter. No general rule can be given to govern this practice and the draftsman should learn to consider

himself in the position of the patternmaker and the machinist and give all dimensions in such a manner as best to serve each of them. It may be assumed for first guidance that the patternmaker uses the radius more than the diameter, and that the machinist uses the calipers to determine the diameters oftener than the radii.

98. Part 2 is very similar in shape to Part 1, except that it is much larger, that the rim is flat—because it is intended to carry a driving belt—and that the arms are straight. Being much like the hand wheel otherwise, the pulley is drawn in much the same manner. The scale used is 3 inches = 1 foot. (See Art. **6.**)

Locate the horizontal center lines $m\,n$ and $r\,s$ (see Fig. 48) $3\frac{3}{8}$ inches and $7\frac{1}{4}$ inches, respectively, from the upper border line, and locate the vertical center line $p\,q$ $4\frac{3}{8}$ inches from the right-hand border line. With o as a center, draw circles representing the outside and inside of the rim and the hub. The outside of the rim will be represented by two circles, an outer one 20 inches in diameter giving the outline of rim at the center, and an inner one with a radius $\frac{1}{8}$ inch smaller giving the outline at the edge. The rim is made higher in the center for the purpose of keeping the belt from slipping off. The amount of rise in the center, that is, the difference between the radius at the edge and that at the middle, or, what is the same thing, the difference between the thickness of the rim at those two points is called the *crown* of the rim, which is seen from the small section at the right-hand lower corner of the plate to be $\frac{5}{16}'' - \frac{3}{16}'' = \frac{1}{8}$ inch. The inside of the rim is perfectly straight and appears therefore in the plan as a single circle drawn with a radius $\frac{5}{16}$ inch smaller than that of the outermost circle. The outside of the hub is also represented by two circles, 3 inches and $3\frac{1}{4}$ inches in diameter, respectively. The diameter of the bore is $1\frac{3}{4}$ inches; this is not indicated in the same manner as the diameter of the hub; that is, by means of a dimension line with arrowheads at both ends. The word bore indicates that the pattern provides for a hole much smaller, so that it can be bored out for any size of shaft within certain

reasonable limits. The dimension given is for the benefit of the machinist.

Now draw the arms. Lay out the center lines *a b*, *a′ b′* of the four arms not horizontal, by means of the 60° triangle. They are tapered, and the small end of each at the rim is $1\frac{3}{8}$ inches across on a tangent to the inside circle of the rim; the large end is 2 inches across at a point $2\frac{3}{8}$ inches from the center. By these dimensions the taper of the arms is established. Hence, draw a perpendicular to the center line of an arm, tangent to the inside circle of the rim, and lay off on it points *c* and *d* $1\frac{3}{8}'' \div 2 = \frac{11}{16}$ inch from the center line on each side. Draw another perpendicular $2\frac{3}{8}$ inches from the center and lay off on it points *e* and *f* 1 inch from the center line. Draw the lines *c e* and *d f*. The limiting lines of the arms are joined at the inner ends by circles of $\frac{5}{16}$-inch radius, lines of adjacent arms being tangent to them. The outer ends of the arms are joined to the rim by fillets of $\frac{5}{16}$-inch radius. Draw in all these fillets. Draw the oval section of the arm at *h i*, Fig. 48, midway between center of pulley and rim.

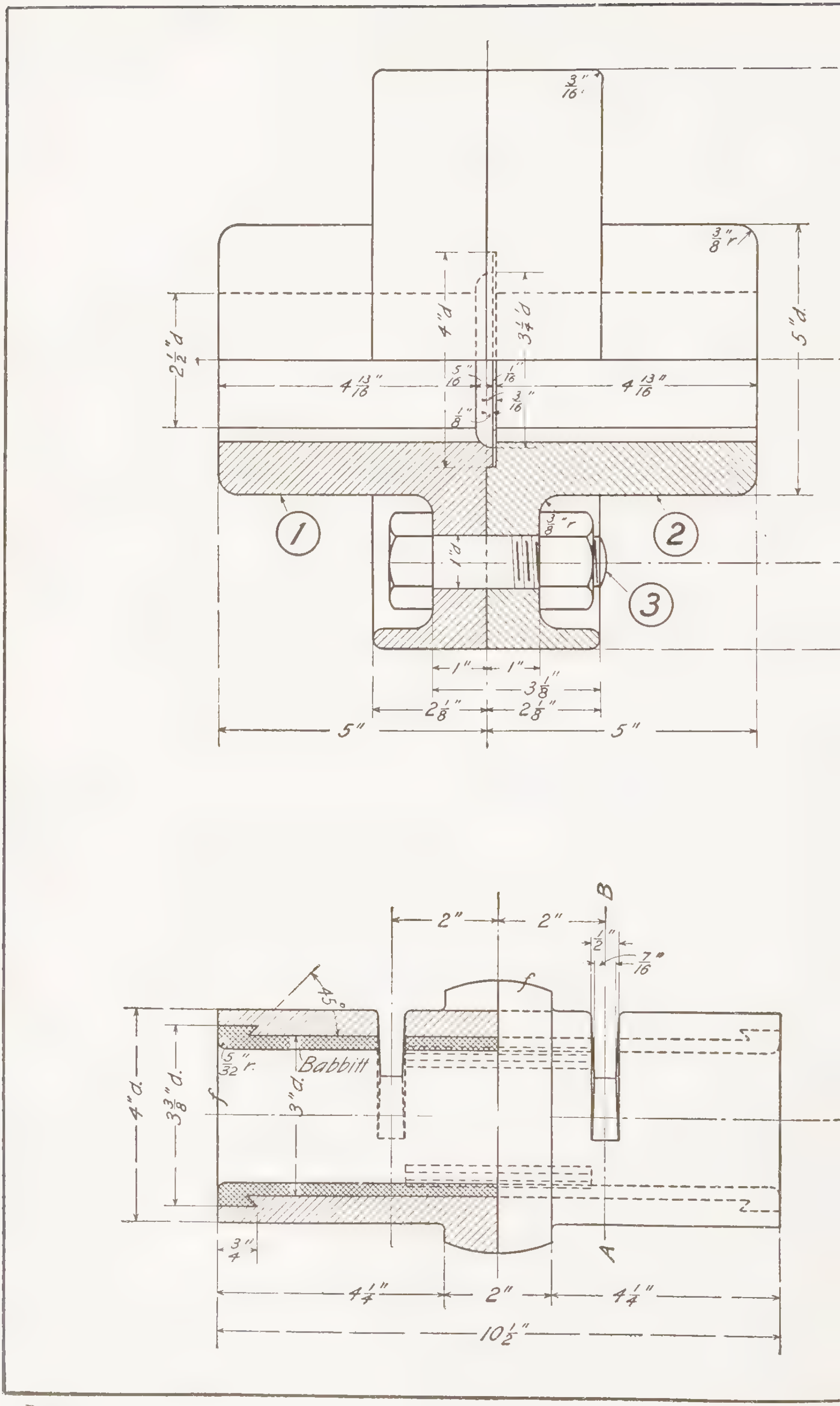
Next draw the lower figure, a sectional elevation, by projecting from the plan the various diameters of rim, hub, and hole, and then laying out the width of the rim, the length of the hub, and the thickness of arms, exactly as was done in the case of the hand wheel.

Note again that only the hub and rim are shown in cross-section on lower view, as it is common practice not to show the arms or any part of them in cross-section, even though a cutting plane be passed through them.

The circles *k*, *k* indicate the positions of the two $\frac{5}{8}$-inch set-screws mentioned in the bill of materials, which fasten the pulley to the shaft. The full circles indicating these holes are surrounded by circles in dotted lines, this being the conventional method to indicate that the holes are tapped.

There should be no difficulty in drawing the large detail section *G H* of the rim.

When finishing the title and bill of materials, note that Part 3 is called for, but is not shown on the drawing, it being a standard piece.



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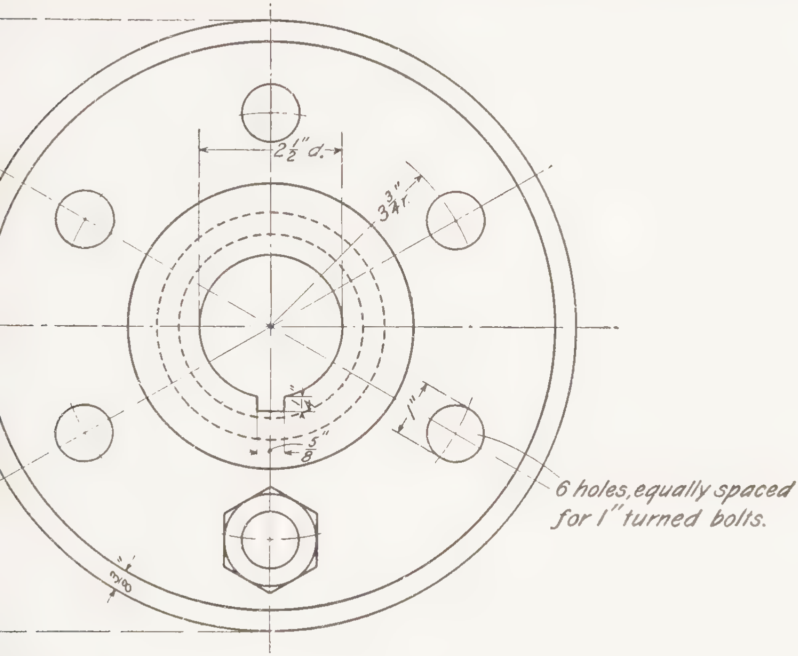
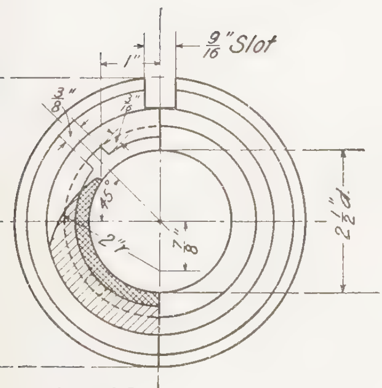


ll over



n on line AB

1	Bearing	4	C.I. and Bab.M.	Pattern	C
6	1" Hex Hd. bolt				
	3¼" long with nut	3	Machine steel		
1	Coupling (female)	2	Cast iron	Pattern	B
1	Coupling (male)	1	Cast iron	Pattern	A

COUPLING AND BEARING

DRAWN BY ....

DATE ....

1006

99. Part **1** requires a pattern to be made. This fact is indicated in the bill of materials by the word *Pattern*, and being the first on the list it is marked *A*. The pattern itself is designated by the number of the drawing and the letter given it, hence it is marked *1005–A*.

Part **2** can be cast from another pattern made from specifications furnished on a drawing numbered 999 and marked *Pattern E* in the bill of materials. Therefore, in the space left for the word "pattern" in the bill of materials and on the same line as the piece referred to, insert *999–E*, thus indicating that a new pattern is not required.

PLATE 1006, TITLE: COUPLING AND BEARING

100. The upper figure of Plate 1006 shows an elevation and end view of a flange coupling used to connect two lengths of shafting. For example, suppose that in a shop or factory there are many machines to be driven from an engine. A belt is carried from the driving pulley of the engine to a pulley on a shaft overhead, which in turn is supported in bearings. This shaft is strung along the whole length of the shop over all the machines to be driven, and pulleys are carried on it from which belts transmit motion to the various machines. It is evident that such a long shaft cannot be made in a single piece and, therefore, it is put up in certain lengths that are connected by couplings. Such a coupling invariably consists of three principal parts, one that is securely fastened to the end of one shaft, a second that is similarly fastened to the end of the other shaft to be connected to the first, and a third part consisting of means to firmly fasten the first two parts together. Fig. 49 shows in perspective the abutting surfaces of such a coupling, and Fig. 50 shows the coupling joined together.

In the flange coupling drawn on Plate 1006 the three principal parts are the flange numbered **1**, the flange numbered **2**, and the bolts, of which there are six, numbered **3**. The flanges are fastened to the shafts by keys, which prevent them turning thereon, and the bolts in turn fasten the two flanges together,

so that the whole structure becomes a solid piece. The coupling is intended for two $2\frac{1}{2}$-inch shafts, and both flanges are, therefore, bored out to that size. The lower part of the elevation shows the coupling in longitudinal section with a bolt in

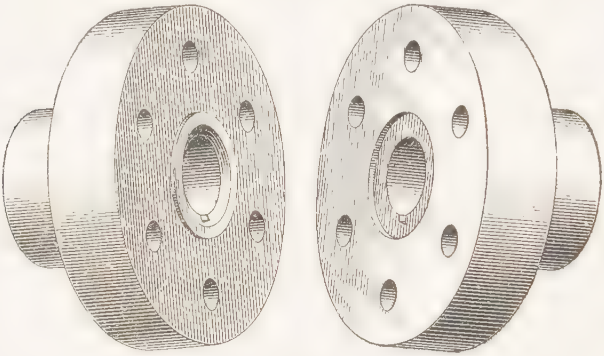


FIG. 49

position. The upper part shows the external view of the coupling, the dotted vertical lines indicating the position of the raised boss on Part **1** which fits into the recess in Part **2**, recess and boss insuring true alinement when the two parts which have been previously keyed to the shaft are bolted together.

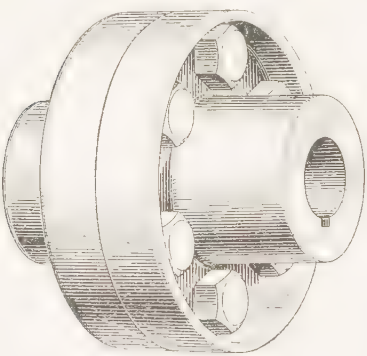


FIG. 50

The two parts of the coupling are first bored and then faced up on the abutting surfaces; the bolt holes are then drilled, the two parts are bolted together, and the keyway is cut. In the end view it will be noticed that but one bolt is shown, and the center lines only for the other five, a note being added stating that there are six holes for 1-inch bolts equally spaced. This is common practice on a working drawing, repeated parts being indicated only and not drawn in full.

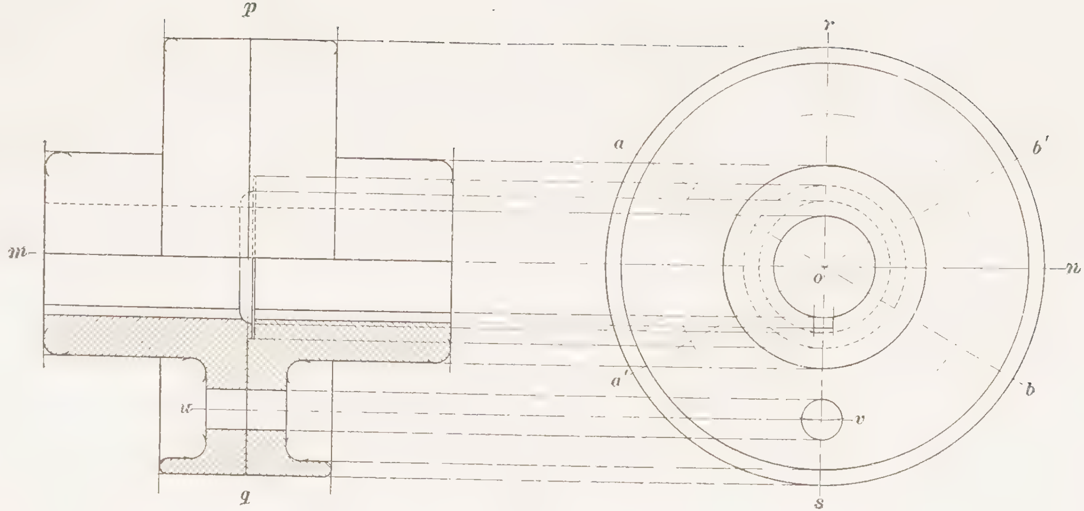


Fig. 51

101. To draw the plate, begin by drawing the center lines. A horizontal center line $m\,n$, Fig. 51, $3\frac{1}{4}$ inches (full size) from the upper border line across the whole sheet, serves for both the left-hand and right-hand views; a vertical center line $p\,q$, $4\frac{1}{2}$ inches from the left-hand border line, represents the joint of the two halves of the coupling; and a third center line $r\,s$ is drawn vertically $5\frac{3}{8}$ inches from the right-hand border line for the right-hand figure, or end view. The scale to be used is 6 inches = 1 foot.

Draw the end view first. With o as a center and a radius equal to $2\frac{1}{2}'' \div 2 = 1\frac{1}{4}$ inches, describe a circle representing the bore for the shaft. Next draw in the keyway, $\frac{5}{8}$ inch wide and $\frac{1}{4}$ inch deep. Two circles described from the same center and having radii of $5'' \div 2 = 2\frac{1}{2}$ inches and $10\frac{3}{4}'' \div 2 = 5\frac{3}{8}$ inches, represent the side view of the hub and the outside of the flanges, respectively. By reference to the lower half of the elevation, it will be seen that the flanges are recessed, leaving a rim of only $\frac{3}{8}$ inch in thickness. Hence, with a radius of $5\frac{3}{8}'' - \frac{3}{8}'' = 5$ inches and a center o, draw a circle concentric with the outside circle, to represent the inside edge of the rim. By means of the 60° triangle draw the remaining center lines $a\,b$, $a'\,b'$ of the bolt holes and intersect them by circular arcs having a radius of $3\frac{3}{4}$ inches. Show the bolt holes in the lower half of the view by drawing circles 1 inch in diameter. Draw the end view of a nut on the middle one of the lower three bolt holes, according to directions given in connection with Plate 1003.

The elevation is now to be drawn. On either side of the vertical center line $p\,q$ lay off 5 inches, the length of hubs of the coupling, and draw vertical lines through the points obtained. Lay off similarly $2\frac{1}{8}$ inches and 1 inch on either side of the vertical center line and draw vertical lines to represent the edges of the flanges and the thickness of the webs of the flanges, respectively; the latter lines may, however, be quite short, as they appear only in the lower half of the figure. Now carry over from the side view, by means of the T square, two horizontal lines, tangent to the outside circle, and intersecting the vertical lines limiting the width of the flanges. Carry over similarly horizontal lines tangent to the circle

representing the side view of the hub. These will intersect the vertical lines limiting the lengths of the hubs; the lower horizontal will also intersect the verticals that limit the thickness of the webs of the flanges. A tangent carried over horizontally from the bottom point of the circle representing the outer outline of the rim will also intersect the verticals in the elevation completing the sectional outline of the coupling. Carry over the horizontal center line $u\ v$ of the bolt from the end view and complete the drawing of the bolt in the usual manner. Round off all sharp corners, using radii as given on the plate. The right-hand half of the coupling has a circular recess 4 inches in diameter and $\frac{3}{16}$ inch deep bored in it; draw this by laying off on either side of the horizontal center line $m\ n$, $4'' \div 2 = 2$ inches, and on the right of the vertical center line $p\ q$ (or, what is the same thing, the face of the flange), lay off $\frac{3}{16}$ inch, and draw the horizontals and a vertical, respectively, through the points. Represent this recess in the end view also, by drawing a dotted circle with a $4'' \div 2 = 2$ inch radius. Into the recess of the right-hand half of the coupling just drawn fits a boss projecting $\frac{1}{8}$ inch from the face of the left-hand half of the coupling; represent this by drawing a vertical line $\frac{1}{8}$ inch to the right of the vertical center line $p\ q$. The verticals representing the bottom of the recess and face of the boss are dotted in the upper half of the figure, as they are hidden there. The left-hand half of coupling has also a circular recess turned in, smaller in diameter than the boss, namely $3\frac{1}{4}$ inches; it is $\frac{5}{16}$ inch deep measured from the face of the boss. Draw in this recess and round its bottom corners; also represent it in the end view by a dotted circle of proper diameter. Next carry over the top line of the shaft bore horizontally from and tangent to the circle that represents the bore in the end view; this line must be dotted in the upper half of the elevation, as it is hidden from view. Finally carry over the bottom lines of the shaft bore and the keyway, shown in full in the lower half of the elevation. Put in the section lining and dimensions.

102. Part 4 on this drawing is a self-alining, self-oiling, dynamo bearing for a $2\frac{1}{2}$-inch shaft. Fig. 52 also shows the

same piece in perspective, which will help to give an idea of its actual appearance. A shaft bearing, generally speaking, is a stationary machine part having a hole into which fits, and in which turns, a movable cylindrical piece, the shaft. Upon a shaft are carried other machine parts designed to turn with it, as, for instance, the armature in a dynamo.

Fig. 52

There are generally two bearings to a shaft of a machine, one on each side of the part carried by the shaft. In order that the shaft may turn freely, the two bearings must be exactly in line all the time. To insure this against any possible distortion of the machine frame or bending of the shaft, bearings are often made self-alining, as the one here represented; that is, they are so located in the frame that they can adjust themselves to any slight variations. This form of arrangement is shown in Fig. 53. Here the adjustment is made by means of the boss *a* (similar to the one that is to be drawn on the plate), whose form is part of a sphere and whose center rests in a correspondingly hollow

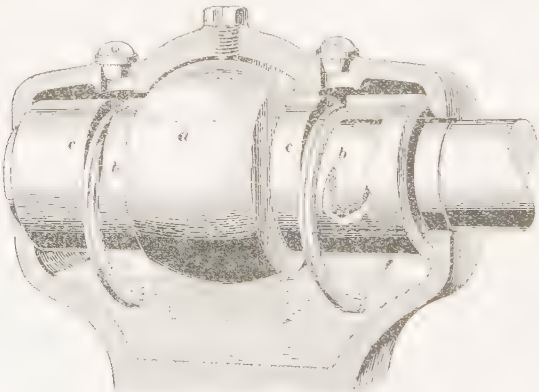


Fig. 53

seat, or socket, in the machine frame. As it rests there, movable of course, friction would be liable to cause the bearing to turn

with the shaft. To prevent this, a slot is cut across the boss *a*, into which fits a pin projecting from the stationary frame.

When two surfaces move, one on the other, they necessarily rub each other, producing friction, and this not only consumes power, but creates heat and is liable to injure the surfaces. The amount of friction varies between different materials, certain combinations offering less friction than others. It has been found that steel shafts move on a softer metal with a comparatively small amount of friction. So bearings are usually lined with Babbitt or similar material. The great expedient, however, to reduce friction, is lubricating the surfaces with oil, which lubrication must be kept up constantly. To reduce the necessary labor of the attendant and to insure constant regular lubrication, bearings are often made self-oiling; that is, are provided with means by which the oiling is done automatically.

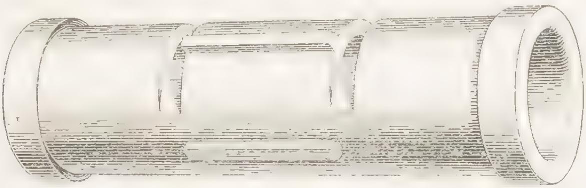


Fig. 54

In the bearing shown in Fig. 53 this is done by hanging over the shaft loose rings *b* that dip into a reservoir of oil, as indicated. When the shaft turns, the rings turn with it by adhesion and carry enough oil from the reservoir to the top of the shaft to oil it properly. In order that the rings may rest on the top of the shaft, the bearing proper must have slots *c c* cut into it. These slots are also shown on the plate and in each of the several views. The bearing shown is made of cast iron and is babbitted inside, the Babbitt being held in place by dovetailed circular recesses at the ends, shown in the left-hand half of the elevation, and longitudinal recesses $\frac{3}{8}$ inch wide and $\frac{3}{16}$ inch deep, shown both in full lines, as well as dotted, in the end view on the plate, and dotted in the elevation. The perspective view in Fig. 54 shows the way the Babbitt would appear in case it was detached from the bearing. The

babbitting is ordinarily done on a mandrel smaller in diameter than the finished bore of the bearing. After being babbitted, the bearing is accurately bored and finally finished on the outside.

The left-hand half of each view on the plate is shown in section, the right-hand half giving the external view. Oil grooves are not shown in the drawing and are omitted from all working drawings when regular shop practice is to be followed, only being added to a drawing if special instructions are to be given.

103. In drawing the bearing, which is drawn half size, proceed in much the same manner as with the coupling. The method of procedure is shown in Fig. 55. Draw the center line $m\,n$ $2\frac{5}{8}$ inches from bottom border line and two vertical

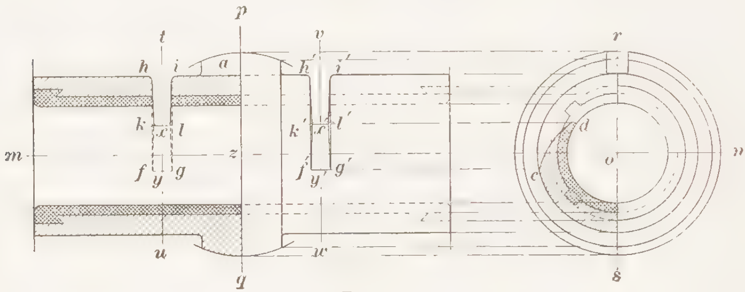


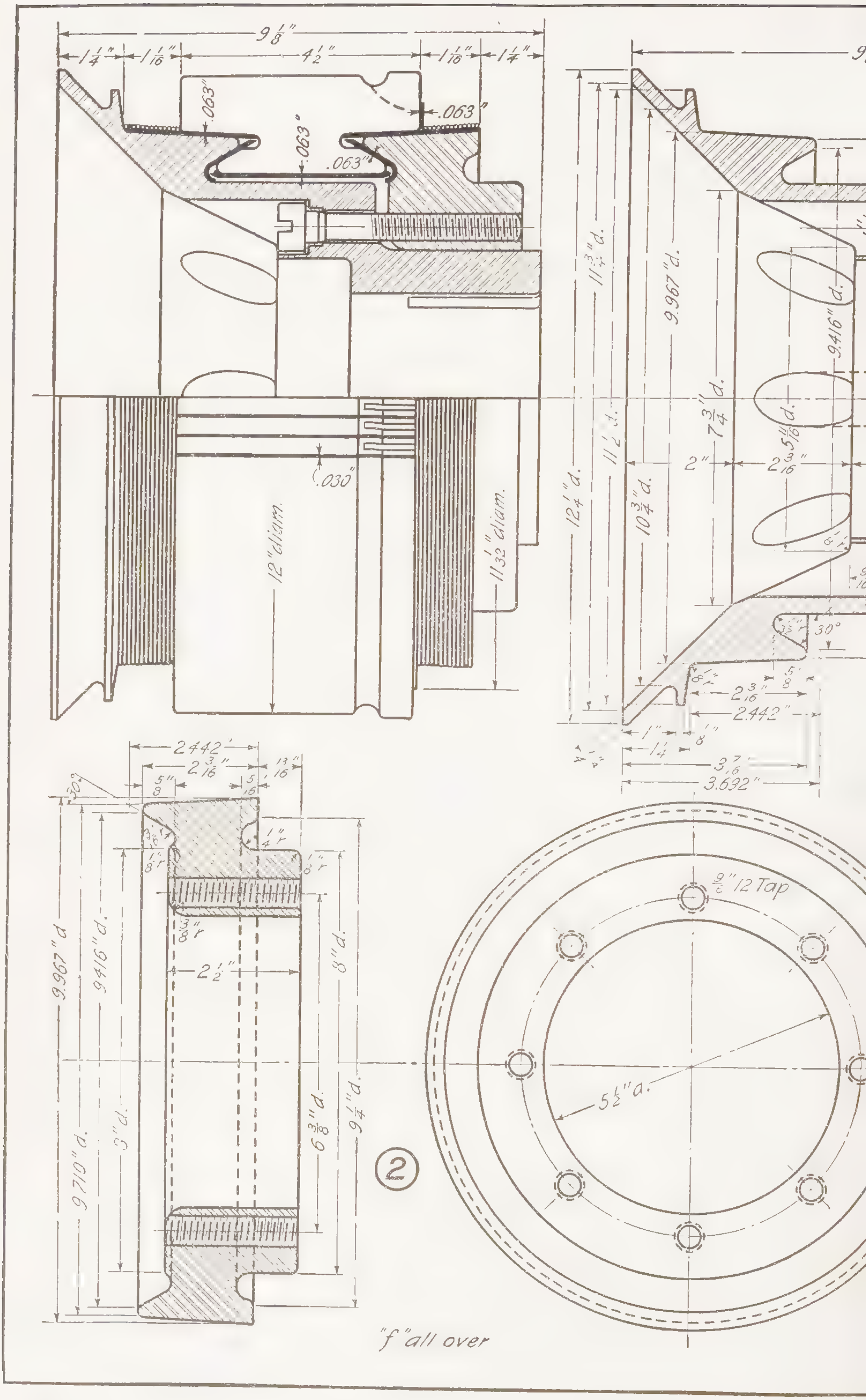
FIG. 55

center lines, one $p\,q$ $4\frac{5}{8}$ inches from the left-hand border line for the elevation, and another $r\,s$ $10\frac{3}{4}$ inches from the left-hand border line for the side view. Begin with the end view, completing it as far as possible, before starting the other view. Thus draw circles with o as a center, $5\frac{1}{8}$, 4, $3\frac{3}{8}$, 3, and $2\frac{1}{2}$ inches in diameter to represent, respectively, the circular outlines of the spherical boss in the center of the bearing, of the body of the bearing, of the outside of the Babbitt lining, and the bore. Next lay off $\frac{7}{8}$ inch from o downwards on $r\,s$ and draw, from this point as a center, a circular arc with a radius of 2 inches. This circular arc cuts into the circles representing the body of the bearing and the bore at c and d. Round off the sharp corner at d. Draw the $\frac{9}{16}$-inch slot on top of the rounded boss. Draw the longitudinal recesses for the Babbitt $\frac{3}{8}$ inch wide and

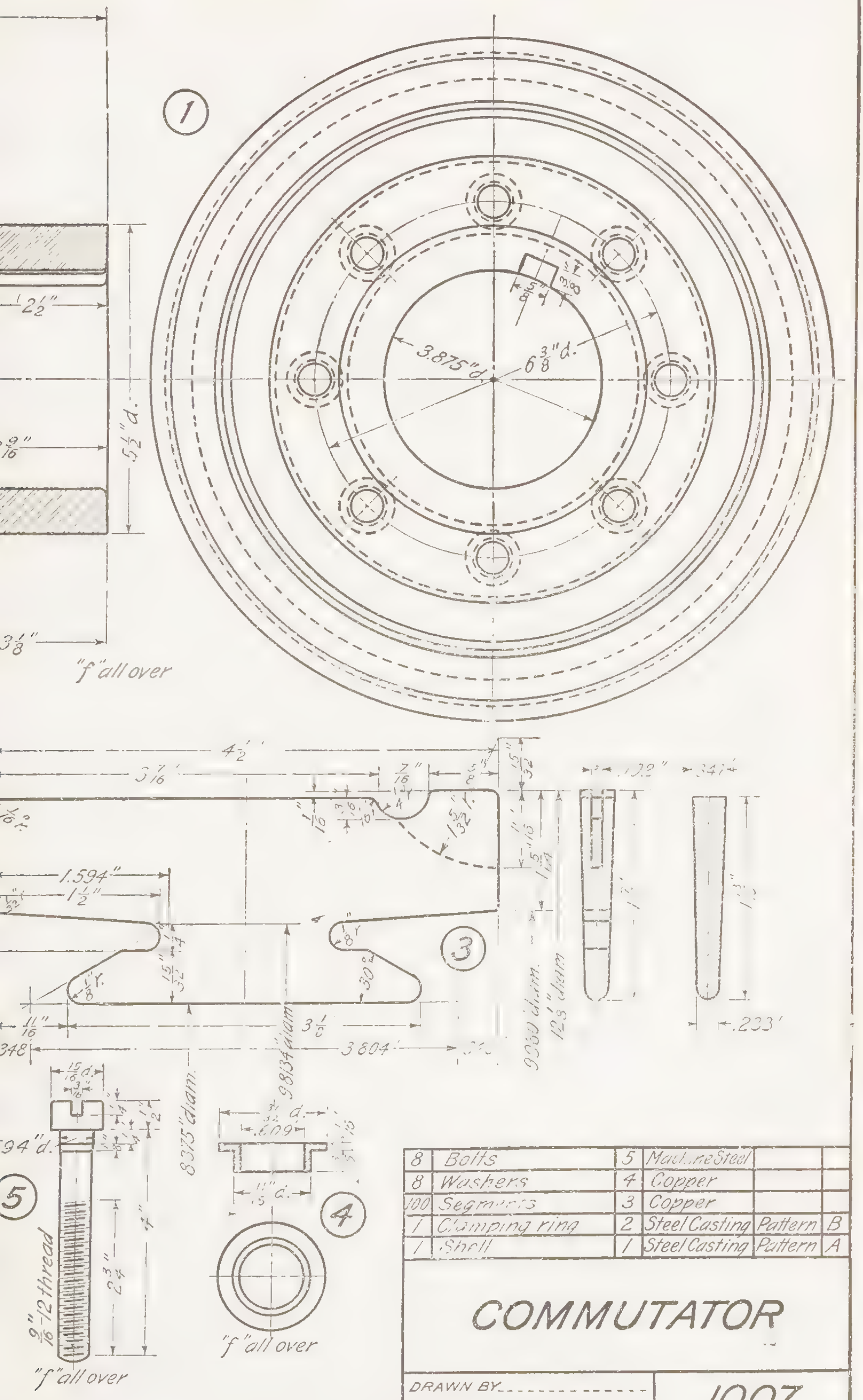
$\frac{3}{16}$ inch deep, their centers 45° from the horizontal center line $m\,n$. Section line the Babbitt and bearing section. This view is now complete with the exception of one circle, namely, that representing the edge of the boss, the radius of which will have to be obtained from the other view, now to be drawn. Carry over horizontally from the end view the lines limiting the diameters of the boss, bearing, Babbitt lining, and bore, tangent to the circles representing these parts in the end view. Lay off right and left from the center line $p\,q$ the various distances limiting the length of the body of the bearing, the boss in the middle, and the lengths of the dovetails of the Babbitt lining. Likewise, lay off 2 inches on either side of $p\,q$ for the center lines $t\,u$ and $v\,w$ of the oil-ring slots. Lay these out next. It will be noticed, from dimensions on the plate, that they are narrower inside, near the shaft, by $\frac{1}{16}$ inch than at the surface of the bearing. These slots are shown slanting to give the ring a free movement. Carry over from the side view a horizontal line through d, which will intersect $t\,u$ and $v\,w$ at x and x', respectively. Lay out the bottom width of the slots at this point, $\frac{7}{16}$ inch, thereby finding the points k, l, k', and l'. Carry over a horizontal from the side view through c, which intersects $t\,u$ and $v\,w$ at y and y', respectively. Lay off the width of the slots at this point, $\frac{1}{2}$ inch. Draw verticals from the points f, g, f', and g' to the upper limiting line of the bearing and intersecting it; from the points of intersection h, i, h', and i' draw lines to the points k, l, k', and l'; also, lines $f\,k$, $g\,l$, $f'\,k'$, and $g'\,l'$. With z, the intersection of the center lines $m\,n$ and $p\,q$, as a center, draw circular arcs limiting the outside of the spherical boss, the radius being obtained by carrying over from the end view or by measurement, $5\frac{1}{8} \div 2 = 2\frac{9}{16}$ inches. The arcs intersect the verticals limiting the length of the boss in points which finally give the radius for a circle to be drawn in the end view to represent the edge of the round boss. Put in the section lining, using the proper lines for cast iron and Babbitt. Notice that the boss is section-lined all through in the bottom half of the figure, but only up to the bottom line of the slot in the top half, showing that the slot runs all the way through the boss.

In completing the drawing, fill in the title and note that two patterns are necessary for the coupling, pattern for **1** being *A*, and for **2**, *B*. Also note that six 1-inch bolts $3\frac{1}{4}$ inches long with nuts are required and are called for in title or bill of material.

The part numbered **4** is made of cast iron, from pattern *C*, and the Babbitt is afterward melted and poured about the mandrel previously spoken of, this mandrel being held in position inside of the casting while the bearing is being babbitted.


12" diam.
.030"
.063"
9.967"d.
9.416"d.
2.442"
3.632"
9.710"d.
8"d.
3"d.
5½"d.
2
"f" all over

Date



8	Bolts	5	Machine Steel		
8	Washers	4	Copper		
100	Segments	3	Copper		
1	Clamping ring	2	Steel Casting	Pattern	B
1	Shell	1	Steel Casting	Pattern	A

COMMUTATOR

DRAWN BY
DATE

1007

MECHANICAL DRAWING
(PART 2)

DRAWING PLATES (Continued)

PLATE 1007, TITLE: COMMUTATOR

104. This plate shows the detail drawings and the assembly drawing of an electric railway-motor commutator. It is composed of a shell, part **1**, and a clamping ring, part **2**, these two parts being drawn together by eight bolts, thereby clamping the 100 commutator bars shown by part **3**. The latter are separated from each other by mica insulation sheets .03 inch thick and are also insulated both from the shell and the clamping ring by mica rings .063 inch, or approximately $\frac{1}{16}$ inch, thick. An idea of the general appearance of the assembled commutator may be had from Fig. 56.

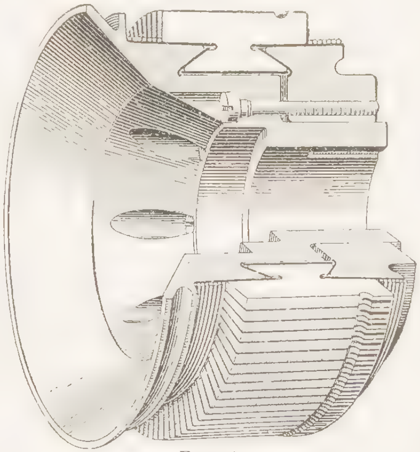


FIG. 56

105. The commutator shell, part **1**, is to be shown in the right-hand upper corner of the plate by means of an end view and a sectional elevation. It is made of steel, cast from pattern *1007–A*. A keyway is cut in one end of the shell, extending into it for a distance of $2\frac{1}{2}$ inches, being $\frac{3}{8}$ inch deep and

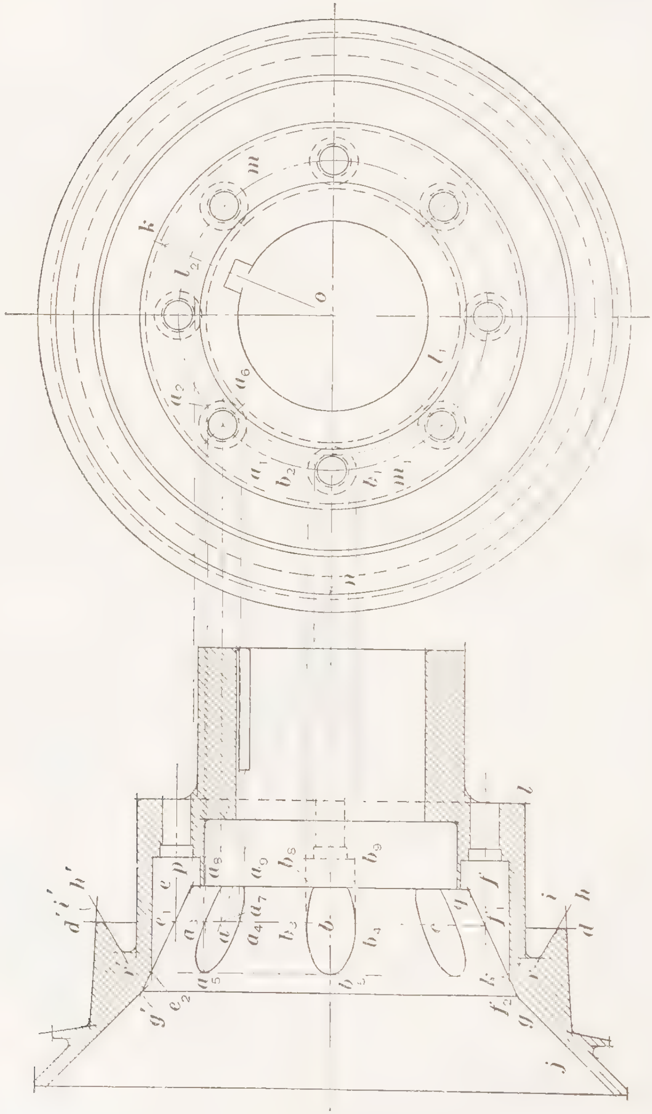


FIG. 37

$\frac{5}{8}$ inch wide. In the sectional elevation no outlines of hidden parts are shown, except such as may serve to make the drawing clearer. This is always desirable practice when lines unnecessarily complicate the drawing without adding any information of value regarding the construction of the piece represented. This part is to be finished all over, as indicated by the note between the two views.

106. Begin by drawing a horizontal center line $3\frac{5}{8}$ inches below the upper border line, extending across the whole width of the plate. Draw the vertical center line of the end view $3\frac{1}{4}$ inches from the right-hand border line, and with the intersection *o*, Fig. 57, of these lines as a center, draw the various circles outlining the bore and the receding surfaces of the shell; the diameters of these surfaces are given in the sectional view of the drawing. The scale to be used is 6 inches = 1 foot. With a radius of $6\frac{3}{8} \div 2 = 3\frac{3}{16}$ inches, draw a circle, around which the centers of the eight holes for the clamping bolts are to be symmetrically located and which are spaced equally distant apart, as indicated. The position of the center line *o k* for the keyway is obtained by drawing two arcs with a radius greater than half the distance between two adjoining holes and connecting the point of intersection *k* with the center *o*. It will be noticed that each full-line circle representing a bolt hole is concentric with two dotted circles, which represent the outlines of the countersunk parts of the holes.

107. Next proceed to draw the sectional elevation of the shell by drawing a vertical line, representing its right-hand end, $\frac{3}{8}$ inch to the left of the end view. Draw another vertical line $9\frac{1}{8}$ inches to the left of the first, thus obtaining two lines that limit the length of the shell. Parallel with these lines draw others that pass through the various external edges of the shell. By projecting horizontal tangents from the top and bottom points of the circles in the end view which represent similar edges, and letting them intersect corresponding verticals in the sectional elevation, the exact locations of the edges are determined. Proceed to outline the internal surfaces of the shell, the bore, and the keyway in a similar manner.

108. It will be noticed that on this plate several dimensions are given to thousandths of an inch. Most of these dimensions refer to the clamping surfaces of the shell, clamping ring, and commutator bars. These parts are turned to fit gauges prepared by the toolmaker, who lays out the gauges and makes them suit the dimensions given. The purpose of giving these dimensions so exactly is to call attention to the fact that great accuracy is required and that measurements at these places are to be determined either by gauges or with micrometers. This practice of giving *accurate* dimensions in decimals and *approximate* dimensions of a machine part in halves, quarters, eighths, sixteenths, etc., of an inch, is now largely adopted in the better class of drafting rooms, the purpose of its adoption being to show the workman at a glance which parts of a machine part require to be very accurate and which do not, thus tending to prevent the waste of time incidental to needless accuracy.

In regard to laying off on the drawing dimensions given in decimals, lay off to the nearest 64th inch, actual measurement. This is ascertained in the following manner: Consider the dimension 9.416 inches in the sectional elevation of part **1.** As the scale used for drawing this is 6 inches = 1 foot, or one-half size, the actual distance to be laid off using a full-size scale is $9.416 \div 2 = 4.708$ inches $= 4 + .708$ inches. But .708 inch expressed in 64ths is $.708 \times \frac{64}{64} = \frac{45.312}{64} = \frac{45}{64}$ inch, to the nearest 64th inch. Hence, the actual distance, measured with a full-size scale, is $4\frac{45}{64}$ inches. Again, part **3** is drawn full size; hence, the dimension 1.594 inches expressed to the nearest 64th inch is $1\frac{38}{64}$ inches, since .594 inch $= .594 \times \frac{64}{64} = \frac{38.016}{64} = \frac{38}{64}$ inch, to the nearest 64th inch.

To find the nearest 64th inch corresponding in value to a dimension given in thousandths of an inch, consult the table given in *Geometrical Drawing*, Part 2.

109. Among the parts demanding great accuracy is the clamping surface indicated by the lines $r\,h$ and $r'\,h'$, Fig. 57.

The correct position and inclination of this surface is determined in the following manner: Draw a vertical line at a distance of 3.692 inches from the left-hand end of the shell and intersect this line with two horizontal lines 9.710 inches apart and equidistant from the horizontal center line, thereby locating the two points i, i'. From these points draw lines $r\,h$ and $r'\,h'$ at angles of 30° with the axis of the shell. Now draw a vertical line $d\,d'$ $3\frac{7}{16}$ inches from the left-hand edge of the shell and find by trial a radius and center such that an arc can be described tangent to $d\,d'$, $h\,r$, and $i\,j$. Also, draw a line parallel to and $\frac{5}{8}$ inch to the left of $d\,d'$ and with a radius of $\frac{7}{32}$ inch find a center from which an arc may be described tangent to this line and tangent also to $h\,r$ and $l\,k$. So proceed with the upper half.

110. As the countersunk parts of the holes intersect the inside of the shell where it is cone-shaped, the outlines of the holes will appear elliptical instead of circular, as indicated by the curves a, b, and c, Fig. 57.

The outlines of the apertures a, b, and c have been carefully defined by a number of points found by the principles of projection. It is not necessary for the student to repeat this construction; it will be sufficient if a few points only are found and the curves are drawn approximately, freehand, through these points. Connect the points e_2 and f_2 by a straight line; the extreme points of the curves will be situated on this line. Likewise connect points e_1 and f_1, on which line points limiting the width of the various curves are to be located. The line $e_1\,f_1$ is a representation of the circle $m\,m_1$. From the points $a_1\,a_2$, where this circle intersects the largest of the circles representing the hole a, draw perpendiculars to the line $e_1\,f_1$. The points of intersection a_3, a_4 are two points on the curve, limiting its extreme width. To find the point a_5 at the extreme end of the curve, produce the line $e_1\,e_2$ until it intersects the horizontal center line of the two views at n. Project the center a_6, in the end view, on the line $e_1\,f_1$; the point of intersection a_7 will be the center of the curve. Draw a line through n and a_7, intersecting line $e_2\,f_2$ at a_5; this point is the extreme end of the curve.

Assuming that the corner at point p is a sharp corner, project this point to the vertical center line of the end view, and through the point thus found draw the circular arc $l_1\,l_2$ with o as a center. This is part of the circle represented by the line $p\,q$. From the points where this arc intersects the circle $a_1\,a_2$, draw perpendiculars to the line $p\,q$; the points of intersection a_8 and a_9 will then locate the inner ends of the curve. Connect the points a_8, a_3, a_5, a_4, and a_9 by a curved line, drawn freehand; the result is the outline of the aperture a.

The location of the curve representing aperture b is somewhat easier to find. From the points of intersection b_1 and b_2 between the circle $m\,m_1$ and the circle indicating the hole b in the end view, draw perpendiculars to the line $e_1\,f_1$, thereby locating the points b_3, b_4. The point of intersection between the line $e_2\,f_2$ and the horizontal center line of the views gives point b_5. To locate the points b_8, b_9, draw projectors from the points of intersection between the arc $l_1\,l_2$ and the circle $b_1\,b_2$ to the line $p\,q$.

It should be noted that while the lines $e_2\,p$ and $f_2\,q$ are here represented as straight lines, they should in reality be flat curves with their convex sides toward the horizontal center line of the view, because the elliptical curve, here shown in side view, does not lie in a plane, but on a conical surface.

Attention is also called to the fact that while in this case the left-hand part of the end view has been used for projection, it is really the right-hand half that is represented in the sectional elevation. The left-hand half was used to avoid drawing projection lines across the whole of the end view.

Outlines of holes, as the above, or curves indicating the junction between intersecting parts, are generally drawn in the manner just described, partly to save time and also because such curves are bound to appear with the proper outlines and in the correct positions on the finished part, as a result of the process of manufacture, irrespective of how they are indicated on the drawings. But there are occasions when the draftsman desires to project such curves in their true form, and he should therefore be prepared to do this with ease and accuracy.

111. The clamping ring, part **2**, is drawn to a scale of 6 inches = 1 foot. It is made of steel, cast from pattern *1007–B*, and slips over the shell at *d*, as shown in Fig. 62. The perspective view in Fig. 58 gives a good representation of this detail. On the drawing it is shown in a sectional elevation and an end view, and the horizontal center line, common for both, should be $3\frac{1}{16}$ inches above the lower border line. First draw the end view, locating its vertical center line $6\frac{7}{16}$ inches from the left-hand border line. It will be noticed that the circles in full lines, indicating the holes, are surrounded by circles in dotted lines. The latter indicate the bottom of the thread in the hole, here $\frac{9}{16}$ inch in diameter, or, what is the same thing, the top of the thread of the screws. The full-line circles indicate the top of thread in the hole or the diameter of the drilled hole, which is .454 inch, or about $\frac{29}{64}$ inch. In the sectional elevation, the threads of the bolt holes are shown left-handed. It is common practice to make the slant of the thread in a bolt hole in an opposite direction to that on the bolt or screw. A space of $1\frac{3}{16}$ inches (full size) should be left between the end view and the sectional view of the clamping ring. In the latter view the tapped holes, shown in cross-section, should in reality have 12 threads per inch, but owing to the small scale to which they are drawn, it is difficult to represent the full number, and they were therefore drawn as shown. The method of laying out the surface *g h*, Fig. 59, with an inclination of 30° to the horizontal center line, is similar to the one described with reference to Fig. 57.

FIG. 58

112. The commutator bar, part **3**, is shown in an elevation, an end view, and in a sectional view taken on line *k l*, Fig. 60; it is to be drawn full size. These commutator bars are made in long strips and are sawed off to proper lengths. The perspective view given in Fig. 61 shows one of the bars as it appears when finished. After the bars are assembled, mica

strips are placed between them, and then the ends of the assembled bars are turned to fit the clamping ring and shell. The majority of the dimensions are very important and are there-

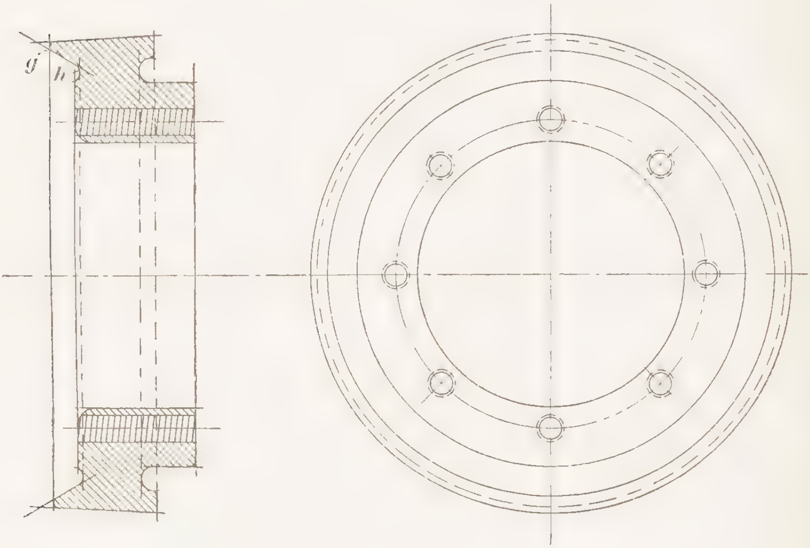


FIG. 59

fore indicated by inches and decimals. Locate the bottom, or base, line *p g* of the commutator bar $3\frac{3}{4}$ inches (full size) above the lower border line and draw the vertical center line *k l*

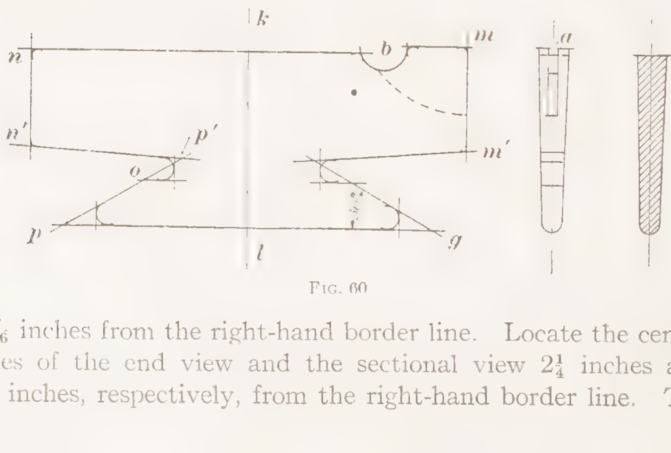


FIG. 60

$5\frac{7}{16}$ inches from the right-hand border line. Locate the center lines of the end view and the sectional view $2\frac{1}{4}$ inches and $1\frac{1}{4}$ inches, respectively, from the right-hand border line. The

drawing of the commutator bar must show the dimensions required by the toolmaker for making the gauges and by the machinist for turning it to size; consequently, some of the dimensions required for drawing it must be obtained by calculation. Before making these calculations, the student should observe the perspective view of the commutator given in Fig. 56, and consider that the commutator bars are clamped together so as to form a solid ring. Thus, the top and bottom of each bar are parts of the outside and inside cylindrical surfaces of this ring, respectively. This will give a clearer understanding of the diametrical dimensions given in part 3 on the drawing plate. The height of the bar along the line $k\,l$, Fig. 60, is given in the sectional view as $1\frac{13}{16}$ inches, but the length of the side $m\,m'$ and the distance of the point m' above the line $p\,g$ must be found by calculation. The point m' is located on a circle the diameter of which is 9.980 inches; as $p\,g$ is tangent to a circle of 8.375 inches diameter, the distance of m' above $p\,g$ is $\frac{9.980-8.375}{2} = .8025$ inch. The length of the side $m\,m'$ is found in the same manner and is $\frac{12.125-9.980}{2} = 1.0725$ inches, or $1\frac{5}{64}$ inches. With the exception of the side $m\,m'$ and the recesses a and b, the two parts of the bar, as divided by the center line $k\,l$, are alike. The point o is located on the line $p\,p'$, drawn at an angle of 30° to $p\,g$, and its distance above $p\,g$ is found by means of the diameters given on the plate. Other points, such as p', are found by means of intersecting lines, the location of which are determined either by a diameter or a distance from one of the boundary lines. The dotted bottom line of the recess in the side $m\,m'$ in Fig. 60 and also shown at the end of the perspective view in Fig. 61 is drawn with a radius of $1\frac{5}{32}$ inches from a center located on $m\,m'$ produced, the lower edge of the recess being $\frac{11}{16}$ inch below the point m.

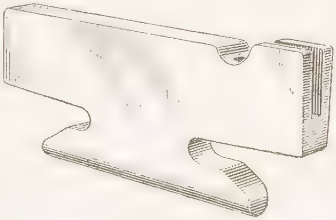


Fig. 61

113. Part **4** is one of the copper washers that fit under the heads of the clamping bolts, thereby making the commutator oil-tight and preventing oil getting from the bearing back of the commutator into the armature. The washer is shown in a bottom view and a sectional elevation. The vertical center line, common for both, should be $5\frac{3}{16}$ inches from the right-hand border line, and the center of the bottom view should be laid off on this line $1\frac{3}{8}$ inches above the lower border line. A space of $\frac{7}{16}$ inch should be left between the two views.

The construction of parts **4** and **5** is not explained by means of any text illustrations, as the student should be able to complete the drawings of both without any supplementary instructions.

114. Part **5** is one of the clamping bolts, the heads of which fit into the holes *a*, *b*, *c*, *e*, *f* in the shell, as shown in Fig. 57. These bolts screw into the clamping ring, and the remarks made about the threaded holes, as to threads per inch, apply also to the bolts. The center line should be $6\frac{15}{16}$ inches from the right-hand border line and the under side of the head should be $2\frac{5}{8}$ inches above the lower border line.

115. The assembly drawing is to be located in the upper left-hand corner of the plate, on the same center line as the shell, with a space of $\frac{3}{8}$ inch between its left-hand boundary line and the left-hand border line. The upper half of this assembly drawing is shown in cross-section. Begin by drawing the shell in the upper half, projecting the various diameters over from the adjoining sectional elevation; then draw the clamping ring and the clamping bolt. The relative positions of these parts are clearly indicated by the dimensions given in the assembly drawing. In Fig. 62 the various mica rings, required for insulating the commutator bars from the shell and clamping ring, are indicated by letters r, r', s, s', t, and u. Each of these rings has a thickness of .063 inch; this dimension has been slightly exaggerated on the drawing, which is permissible on working drawings. Those parts of the two mica rings r, r' that extend beyond the ends of the commutator bars are securely fastened in place by twine, well shellacked.

The lower half of this view, in which the vertical outlines may be obtained by projection from the upper half, may now be drawn. But few commutator bars are shown in this assembly drawing, as it is not customary to spend the time required to indicate the positions of all the bars. To space the bars properly, draw the semicircle *a b c*, Fig. 62, with a diameter of 12 inches, that being the diameter of the commutator at the middle of the commutator bars. Divide the quarter circle *b c*

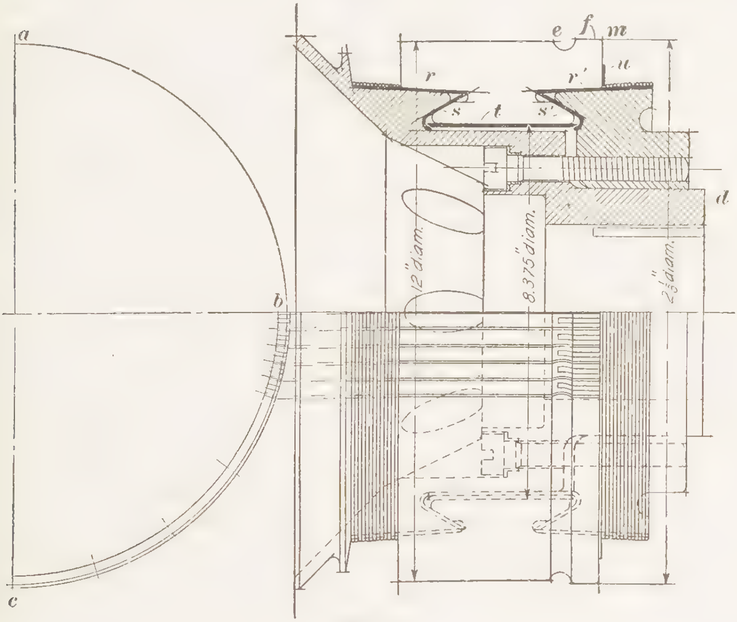


FIG. 62

in five equal parts, and the part next to *b* again in five parts. At either side of these division lines, lay off one-half of the insulation thickness, which leaves in each division a space equal to one bar. At the middle of this space mark off the width of the recess; viz., .102 inch Lines projected across from the first 12 divisions will locate the first three bars in the assembly drawing. The projections of the arcs *e* are flat curves near the center line, but will increase gradually in curvature as the segments get farther away.

In cases where it is desirable to lay off all the bars and every part of the same correctly, the following method may be pursued: Draw the semicircle *a b c* as before, but add the two quarter circles, shown in Fig. 62, the outside one having a radius equal to the distance of the point *m* from the commutator center, and the inside one with a radius equal to the distance between the bottom of the recess *e*, near the ear *f*, and the commutator center. Divide the quarter circle *b c* as before, but continue the subdividing down to point *c* and make the dividing lines long enough to intersect all three arcs. In Fig. 62 this has been done only in the upper fifth of the arc. Projecting lines are now drawn, as before, those from the inner arc indicating the lowest points in the groove. Through these points and the adjoining edges draw circular arcs, the radii of which may be found by trial.

The pencil drawing is now complete and the plate is ready to trace.

PLATE 1008, TITLE: STEEL GIRDERS

116. The methods and conventions employed in making mechanical drawings are not all the same in the various branches of engineering, as, for instance, in structural engineering, which concerns itself mainly with the construction of columns, girders, braces, etc. used in the construction of bridges, modern office buildings, etc. As an example of structural construction, the shop or working drawing of several special, built-up steel girders has been selected, by means of which the methods employed in the execution of this class of drawings will be shown.

Before proceeding with the drawing the student should familiarize himself with the names and purposes of the several parts, as given in the following description.

117. In Fig. 63, which is a perspective view of a part of a girder, the angles marked *a* are the **flange angles**, the upper pair forming the **top chords** and the lower the **bottom chords** of the girder. Connecting these chords is the **web-plate** *b*. Vertical angles located as at *e* and *d* are known as **stiffeners.** Two stiffeners are required at the ends of the girder for the

purpose of strengthening the web at the points where the girder is supported. At *d* stiffeners are also placed to reinforce the web, because at this point the upper chord of the girder is supporting the concentrated load presented by a column, the rivet holes for which are shown in the top chords above the stiffener *d*. At *f*, *f* are shown packing pieces, commonly called **fillers,** from the fact that they are used to fill a space otherwise open, which is undesirable where a compactly built-up part is required. These fillers are used wherever it is necessary to rivet through a space that would otherwise be vacant. **Reinforcing plates,** such as *g*, are frequently used to further stiffen the web of a plate girder, at the places adjacent to the

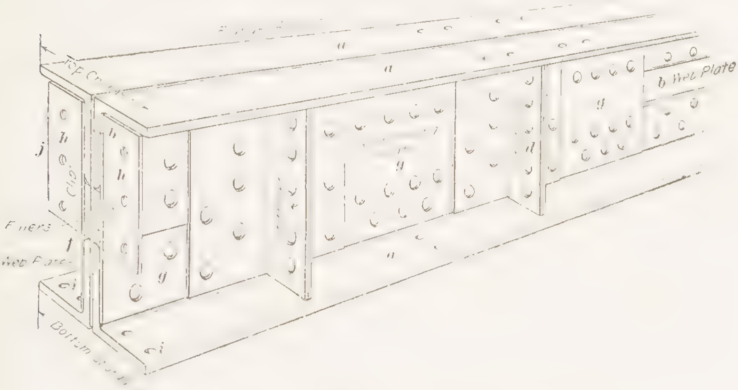


FIG. 63

points of support and beneath concentrated loads. The end *j* of the girder is to be secured to a structural steel column, and for this purpose the angle-iron **clips** *h*, *h* and the holes *i*, *i* through the lower flange angles are provided.

The structural girder under consideration is peculiar in that its depth is very small in comparison with its span, in consequence of which the girder is heavy for the load it is required to support. The necessity for keeping the girder shallow is that it may not diminish the **headroom**, or height, of the room beneath.

118. In Plate 1008, the conventional method of representing shop and field rivets, as explained in connection with

Plate 1001, is used. It will be noted that when a hole for a field rivet is shown in elevation it is indicated by a blackened rectangle, as in the sectional view on the plate. In the perspective view, Fig. 63, holes for field rivets are shown in the upper chord over the stiffener *d* and in the lower chord to the left of *e* and *d*, also in the clips *h*. These same holes are indicated in black in the various views on the plate.

119. The plate represents the working drawings of four separate girders, the shortest being 15 feet $1\frac{3}{4}$ inches, and the longest 17 feet $3\frac{1}{4}$ inches in length. It would evidently be impossible to show each of these girders complete and at the same time to a scale large enough to make a readable drawing, without requiring an unnecessarily large sheet. To obviate this the girders have been divided into several sections and some parts broken away, as being simply duplicates of the part remaining. In this manner one drawing may be made to represent four different girders. The method of indicating the places where breaks occur differs from that heretofore described. It is here indicated by drawing a line consisting of a long dash and a dot along the adjoining parts of the break. Adjoining sections need not necessarily be arranged in one row, but may be placed in several rows, in this manner making the drawing still more condensed. On this plate the first section is placed by itself and the line of break marked with the line *X X*. The remaining three sections are placed in a row below, in which the first section also has a line *X X* indicating that this end is to be considered as contiguous to the one similarly marked. The parts removed by the two breaks in the lower row contain a number of rivet holes, which are spaced similarly to those in the remaining parts; it would therefore be superfluous to show them. The scale to be used is $1\frac{1}{2}$ inches = 1 foot.

120. The distance between the centers of two rivets is called their **pitch**, commonly designated on the drawing by the word **space**. The space need not necessarily refer to the spaces between rivets in one row, but may also refer to spaces between alternate rivets in two parallel rows. For instance, in the upper elevation, near the middle, are shown several

spaces marked $4\frac{1}{2}''$, meaning the spaces between two alternate rivets in separate rows. In the lower elevation, beginning at the left, is found the note "31 alt. spaces @ $2\frac{1}{4}''=5'-9\frac{3}{4}''$;" this means that the drawing should show thirty-two rivets alternating in two rows and spaced $2\frac{1}{4}$ inches apart and that the distance between the centers of the first and the last rivets in one series is 5 feet $9\frac{3}{4}$ inches. The rivets in each row have a pitch of $4\frac{1}{2}$ inches. The saving in length by this method is evinced by the fact that the drawing shows only nineteen spaces of the thirty-one required. Each series is made up of as many rivets as possible without including rivets of a different pitch. As soon as a change takes place in the pitch a new series is arranged, as found, for instance, to the right of the note just referred to, where the following note is found: "17 alt. spaces @ $1\frac{1}{2}''=2'-1\frac{1}{2}''$," meaning that the spacing has been reduced from $2\frac{1}{4}$ inches to $1\frac{1}{2}$ inches.

121. In the drawing, the four girders are designated by the marks *E 1*, *E 2*, *F 1*, and *F 2*, but these marks are only to be found under the lower three sections, at which place all changes have been made both as to spacing of rivets and difference in length of girders. The left-hand parts of all four girders are alike and therefore no distinction need here be made between them. The marks *E 1*, *E 2*, *F 1*, and *F 2* are shop marks and are usually painted on the work in white lead before they leave the mill. To them the erector refers in placing the work in position, as the marks correspond with similar marks on an assembly drawing used in erecting the work in the field.

122. The dimensions of the various angles used in constructing the girder are not given in detail, they being unnecessary on a working drawing. All that is required is to give the size of the angles. The note on top of the left-hand part of the girder, "2 L's $6''\times3\frac{1}{2}''\times\frac{3}{8}''-0'-9''$ long," means that the part indicated is made up of two angles, or L's, 9 inches long and having legs 6 inches and $3\frac{1}{2}$ inches long, respectively, each of which is $\frac{3}{8}$ inch thick. These angles come in lengths of about 15 to 20 feet and can afterwards be cut in smaller lengths, as required.

The fillers are also cut from long bars varying in width and thickness according to the space to be filled. For instance, the note "$3\frac{3}{4}'' \times \frac{3}{4}''$ Pl. 1′-6″" at the head of the girder means that the filler plate is to be cut from a bar $3\frac{3}{4}$ inches wide by $\frac{3}{4}$ inch thick, and to a length of 1 foot 6 inches.

It will be noted that the manner of indicating dimensions given in feet and inches on this plate differs from that used on the other plates described in this Section. Thus, instead of expressing 5 feet $6\frac{1}{4}$ inches as 5 ft. $6\frac{1}{4}''$, it is here expressed $5'$-$6\frac{1}{4}''$, in conformity with the working drawing from which the plate was made. The former method is to be preferred, but if the latter is used, never omit the short dash between the feet and inches.

In order to aid the student in drawing the angles in the chords, the dimensions of which are not fully given on the plate, a sectional perspective view of one, fully dimensioned, is given in Fig. 64. The radii of the fillet and corners are more or less arbitrary, the various rolling mills having their own standards.

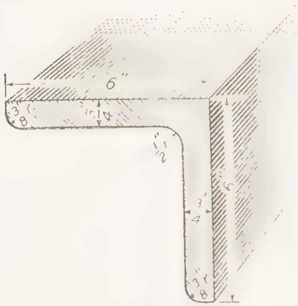


FIG. 64

The rivets used in this girder have $\frac{3}{4}$-inch and $\frac{7}{8}$-inch shanks with heads $1\frac{1}{4}$ inches and $1\frac{7}{16}$ inches in diameter and $\frac{9}{16}$ inch and $\frac{39}{64}$ inch high, respectively. The holes for the rivets are generally punched $\frac{1}{16}$ inch larger than the shank, the size of a rivet being indicated by the diameter of the shank *before* the rivet is driven. All $\frac{3}{4}$-inch rivets require holes $\frac{13}{16}$ inch in diameter. The rivets when driven fill these holes; consequently the *driven* size of a rivet = nominal size + $\frac{1}{16}$ inch. At the places where field rivets are to be driven, the notes "$\frac{13}{16}''$ holes" are to be found, indicating that $\frac{3}{4}$ inch rivets are to be used.

123. To draw the plate, begin by drawing the sectional elevation of the girder, Fig. 65 (*a*). This section is taken along the line *A B*, Fig. 65 (*b*), and shown as it would appear when looking along the girder from the right-hand end. Locate the

FIG. 65

center line $m\,n$ $1\frac{11}{16}$ inches from the right-hand border line, and the top line $o\,p$ $3\frac{3}{4}$ inches below the upper border line. Lay off one-half the thickness of the web-plate b to either side of center line and draw the four angles a_1, a_2, a_3, and a_4, according to the dimensions given in Fig. 64.

Between the upper and lower angles insert the two fillers f, f'; then add the reinforcing plates g, g'. The note "2–14″×$\frac{3}{8}$″ –4′–4$\frac{5}{8}$″" just below bottom chord refers to this part and means 2 plates 4′–4$\frac{1}{2}$″ long, 14″ wide, and $\frac{3}{8}$″ thick. Finally draw the clips c, c'. It should be noted that the reinforcing plates g and g' extend only to where the curve of the fillets on the chord angles begin, while the stiffeners shown in front elevation have to extend clear to the angles of the top and bottom chords, and for this reason have their inner corners chipped off. Draw the center lines of the rivet holes, and indicate their location by blackened rectangles or circles where field rivets are to be indicated. On structural drawings it is customary to indicate cross-sections by section lines; or they are filled in entirely, either with ink or some dark color. If thus filled in, the spaces indicating field rivets are left white.

The note "Finished Third-Floor Line," found over the sectional elevation, means that the floor above the girder, when laid, will come to a height indicated by the line of dashes.

124. Next draw the elevation of the first section of the girder, locating its left end $\frac{7}{8}$ inch from the left-hand border line. The limiting lines of the top and bottom angles may be projected from the section just drawn, likewise the lines limiting the width of fillers and reinforcing plates. Next locate the center lines $q\,r$ and $s\,t$ of the stiffeners d and e, as in Fig. 65 (b), and lay off their total width; also the sides of the legs d_1, d_2, e_1, and e_2, which project outwards at right angles to the plane of the paper. Lay off the clips c, one leg of which is seen to project a distance of $\frac{3}{8}$ inch beyond the end of the girder. By referring to the sectional elevation, it will be noticed that the top of the clips is 1 inch below the upper side of the chord. Draw the reinforcing plate g extending from g_1 to g_2. Indicate the fillers f_1 and f_2, the first being of a length equal to

the width of *d*, and the latter of a length equal to the combined width of *c* and *e*. These fillers are covered both by the stiffeners and the reinforcing plates, and must therefore be indicated by dotted lines, which are shown beyond the edges of the stiffeners in order that they may be seen, though in reality they coincide with the edges of the stiffeners. Lay off the section line X X at a distance of 8 feet $5\frac{3}{8}$ inches from the left-hand end of the girder.

All the rivets in the front elevation are located in six horizontal rows at the distances from upper side of girder indicated on the plate. Draw these horizontal center lines. Select any one of these lines, as, for instance, the lowest, and lay off on same the distance between centers of rivets, as given in any one of the rows below the girder, all of which are seen to be alike. From the lowest center line, verticals are drawn by means of the **T** square and triangle to the other center lines, intersecting them at the proper places and thereby locating the centers of the various rivets. It is unnecessary in the pencil drawing to draw the circle representing the rivets; this may be postponed to the making of the tracing, when the intersections of the rivet center lines will indicate the positions of the centers around which to draw the little circles. In some shops it is customary to omit these circles altogether and simply indicate the positions of the rivets by their center lines.

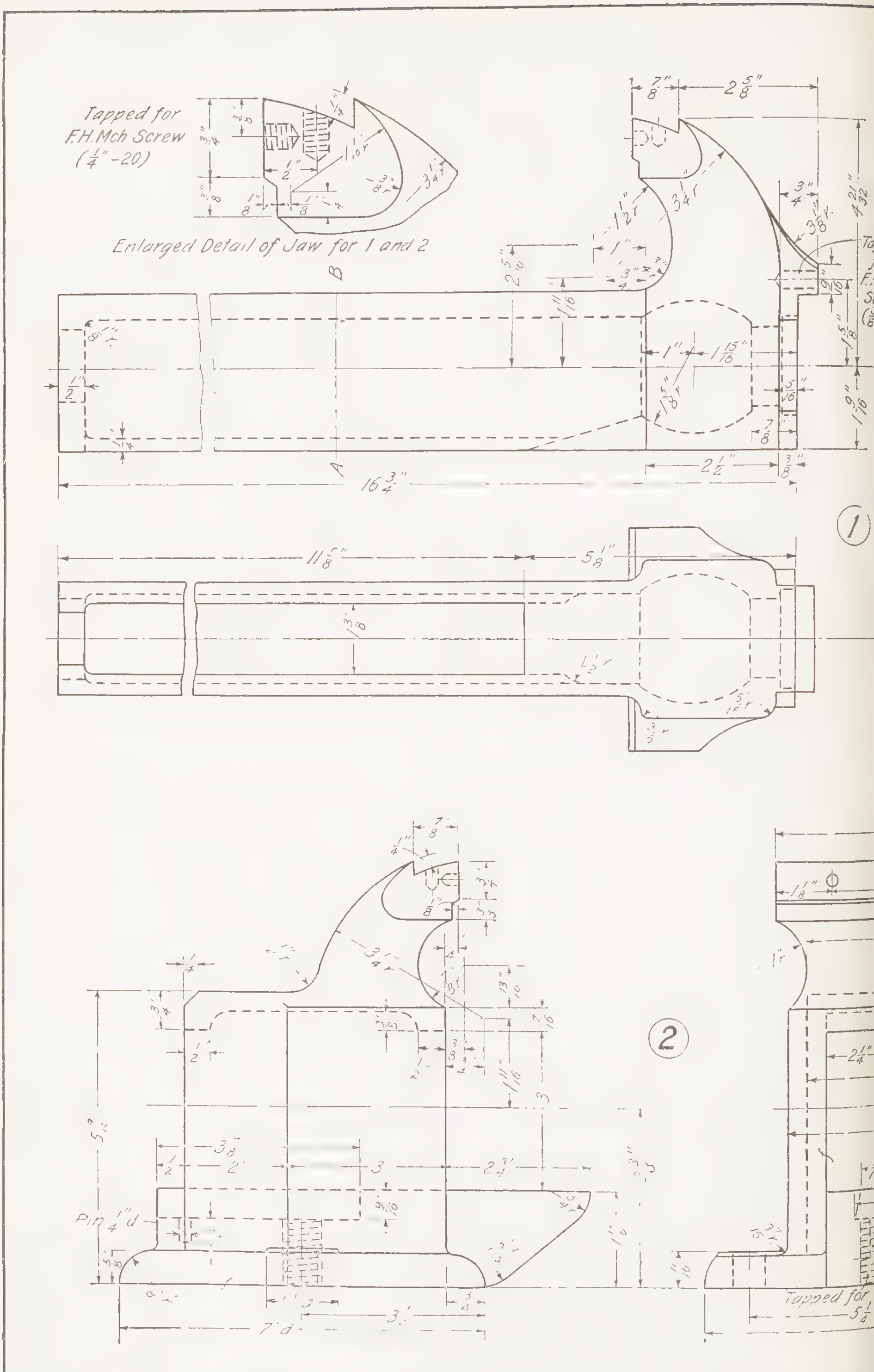
125. The first of the two plan views of the girder, shown in the upper part of the plate and in Fig. 65 (*c*) may now be drawn by first laying off the center line u v $1\frac{11}{16}$ inches below the upper border line. Locate the left-hand end by drawing a vertical line from the corresponding end in the elevation and locate the section line at its right-hand end, 8 inches from the left-hand border line. The length of those angle legs which stand at right angles to the center line u v may be found by consulting the notes in the elevation. The holes for the field rivets will in this view appear as circles which are to be blacked in. The locations of the other limiting lines are found partly by projection from the elevation and partly by transferring the measurement from the sectional end view, Fig. 65 (*a*).

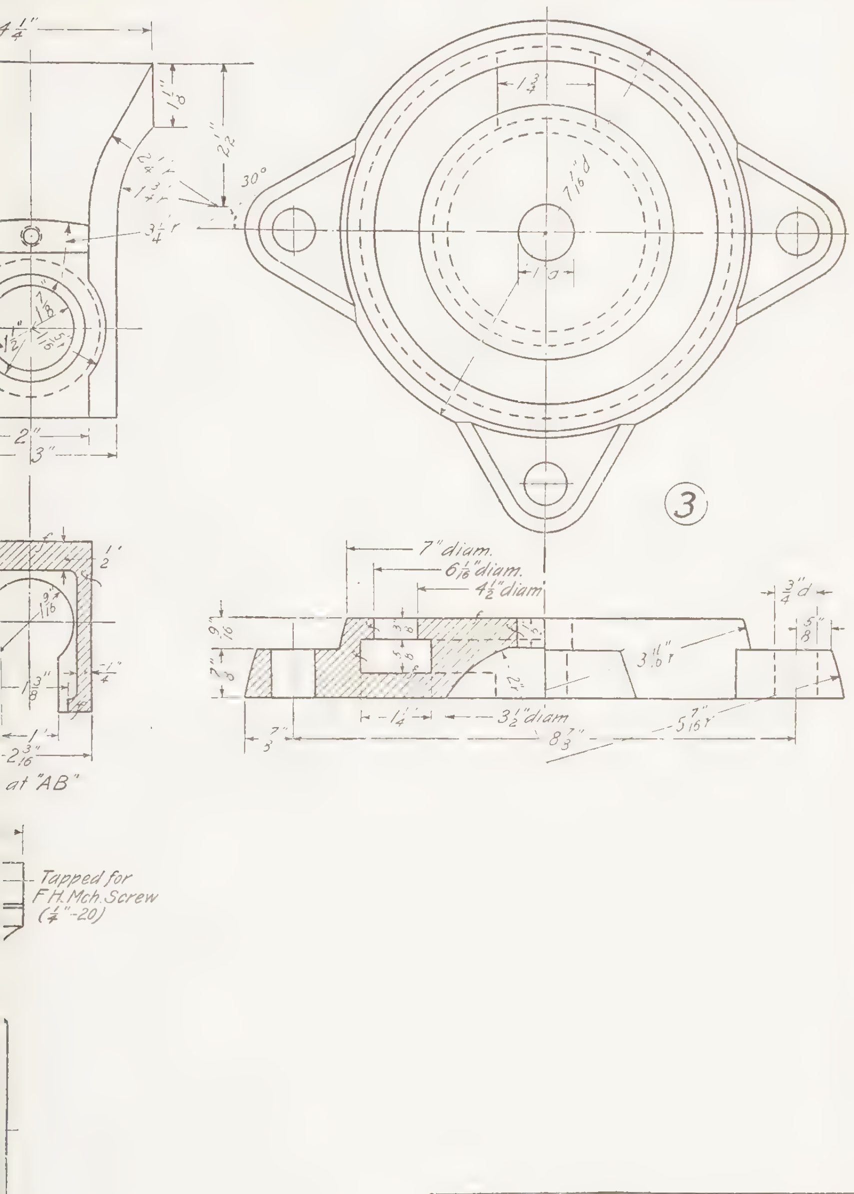
126. The other plan view, see also Fig. 65 (*d*), shows the girder in a sectional view taken along an imaginary horizontal line *C D* in the elevation on the plate. The view is similar to the one previously drawn, except that some of the parts are shown in full instead of dotted lines. Most of the limiting lines are found by projecting horizontals from the other plan view, the position of the remaining limiting lines being determined by direct measurement; all dimensions extending in a horizontal direction are found in this manner. Those field rivets in the lower chord that are not visible in the other plan are here indicated, likewise those in the clips.

127. Next proceed to draw the right-hand parts, see also Fig. 65 (*e*), of the four girders. Locate the lower side of the same $2\frac{3}{8}$ inches above the lower border line, letting the left-hand end lie in a line with the same end of the other elevation. This elevation is divided in three sections. Make the first section 3 inches, the second 4 inches, and the third $2\frac{25}{32}$ inches long, leaving a space of $\frac{5}{32}$ inch between each section. In other respects this elevation is drawn in the same manner as the one immediately above it. Locate the stiffener *h* 3 inches from the right-hand end and add the filler *i*, here shown in full lines.

128. Now put on the dimensions, taking care in arranging the dimension lines that indicate the lengths of the girder and girder sections. In the bill of materials on the plate, the lengths of the girders are given. These lengths are the lengths of the rolled beam itself and do not include any parts attached. For example, the length of the girders *E 1* and *E 2* is given as 15 feet $1\frac{3}{4}$ inches; while on the drawing the dimensions show their over-all length to be 15 feet $2\frac{1}{8}$ inches, the additional $\frac{3}{8}$ inch being due to the clips riveted to the left-hand end.

Between the break line *X X* of the lower elevation and its right-hand end there are found three pair of dimension lines, the first of which refers to the girders marked *E 1* and *E 2*, the second to girder *F 2*, and the third pair to girder *F 1*. In each pair the upper line refers to the spacing of rivets and the lower to the total length of the section. Locate the first dimension line $\frac{1}{2}$ inch below the girder, the second line $\frac{7}{16}$ inch below


Tapped for
F.H. Mch Screw
(1/4"-20)
Enlarged Detail of Jaw for 1 and 2
16 3/4"
11 5/8"
5 1/8"
1
2
Pin 1/4" d
7" d
Tapped for

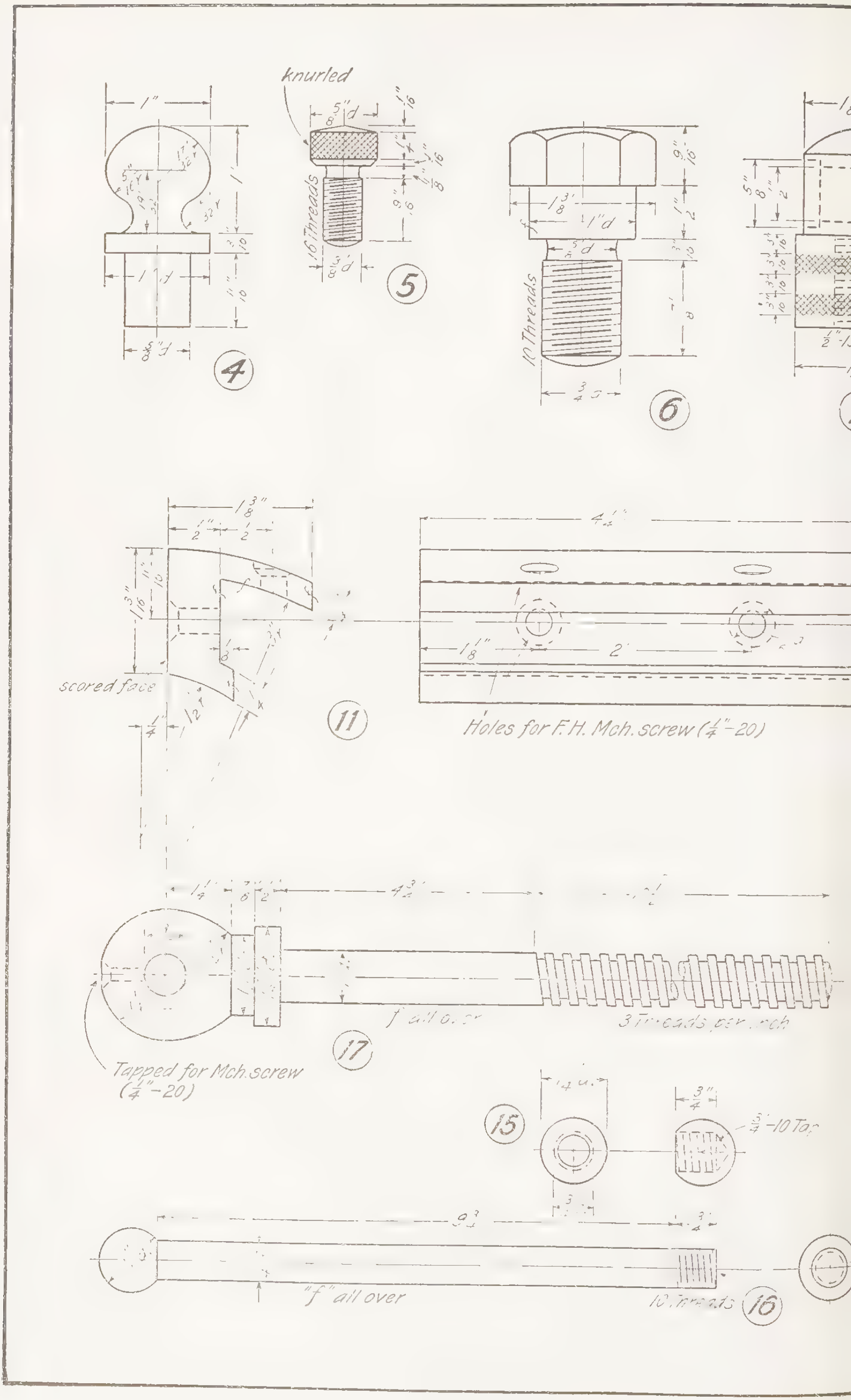


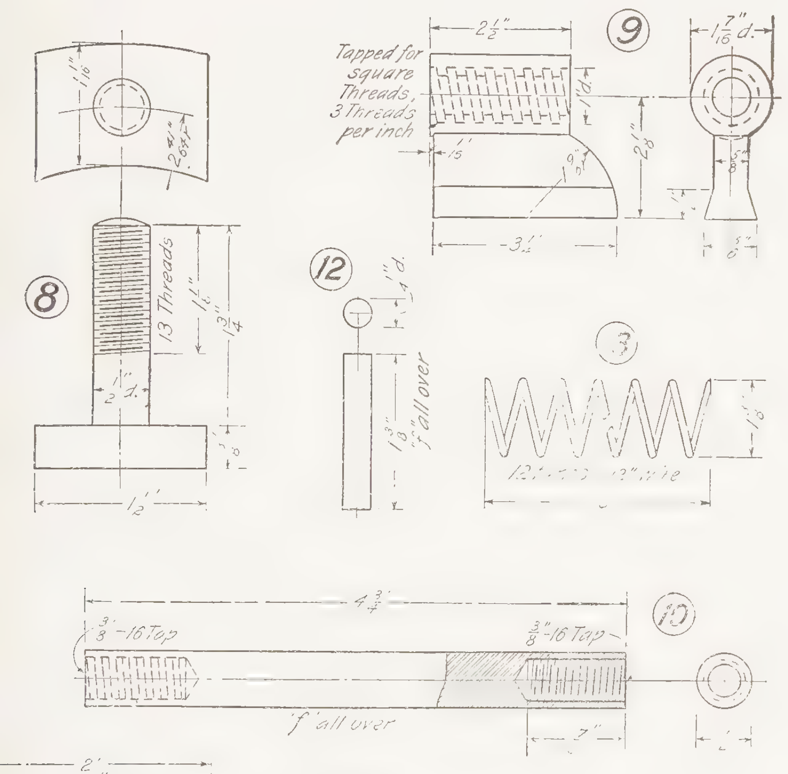
1	Base	3	Cast Iron	Pattern	C
1	Jaw	2	Cast Iron	Pattern	B
1	Jaw	1	Cast Iron	Pattern	A

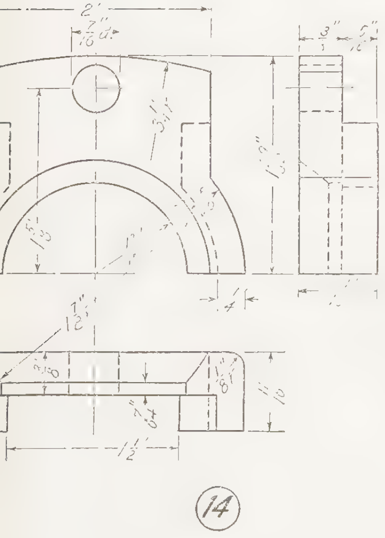
BENCH VISE
DETAILS-I.

DRAWN BY ----------
DATE ----------

1009


knurled
16 Threads
10 Threads
4
5
6
scored face
11
Holes for F.H. Mch. screw (1/4"-20)
17
Tapped for Mch. screw (1/4"-20)
15
"f" all over
16





1	[illegible]	20	Machine steel		
1	Fil H. Mch screw $\frac{3}{8}$-16-$\frac{7}{8}$ long	19	Machine steel		
8	$\frac{1}{4}$ 20 FH Mch screw for 12 & 11	18	Machine steel		
1	Vise screw	17	Cast steel	Pattern	G
1	Rod for 17	16	Machine steel		
1	Nut for 16	15	Machine steel		
1	Guard for 1	14	Cast steel	Pattern	F
1	Spring for 9 & 12	13	Steel		
1	Stop Pin for 2 & 9	12	Machine steel		
2	Jaw Face for 1 & 2	11	Cast steel	Pattern	E
1	Rod for 1	10	Machine steel		
1	Nut for 17 & 2	9	Cast iron	Pattern	D
1	Clamp[illegible] for 7	8	Machine steel		
1	Sleeve Nut for 8	7	Machine steel		
1	Clamping Bolt for 2 & 3	6	Machine steel		
2	Screw for 10	5	Machine steel		
1	Pin for 2	4	Machine steel		

BENCH VISE DETAILS-II.

DRAWN BY __________

DATE __________

1010

the first, and leave a space of $\frac{3}{16}$ inch between each of the remaining lines. The dimension lines found under the other elevation of the girder, represented by Fig. 65 (*b*), are supposed to be continuations of these six lines and should be located in the same manner. Draw the other dimension lines and insert corresponding dimensions, following closely the method used on the plate as to their location and style of lettering. Add the notes referring to rivets and holes and the one referring to number and marks on girders. Lay off the space required for bill of materials by drawing horizontal lines $\frac{5}{32}$ inch apart. The lettering in this case is to be $\frac{3}{32}$ inch high. The vertical subdivisions, measured from the left end, will be $\frac{3}{8}$, $\frac{1}{4}$, $\frac{9}{16}$, $\frac{9}{16}$, 1, and $1\frac{1}{4}$ inches. The abbreviations "Fill" and "Stiff" refer to fillers and stiffeners, respectively. *R* and *L* means right and left. When parts symmetrically placed are marked in this manner, it calls attention to the fact that they are not alike and that care should be exercised in order to put them in their proper places.

PLATES 1009 AND 1010, TITLE: BENCH-VISE DETAILS

129. Plates 1009 and 1010, together with Fig. 67, give the details and assembly drawing of a bench vise. In actual prac-

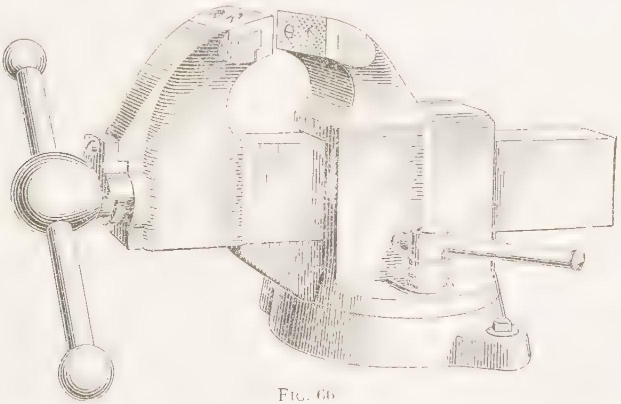


FIG. 66

tice the assembly drawing, Fig. 67, would be drawn first, but in this case it is desirable to draw the details first, as a clearer

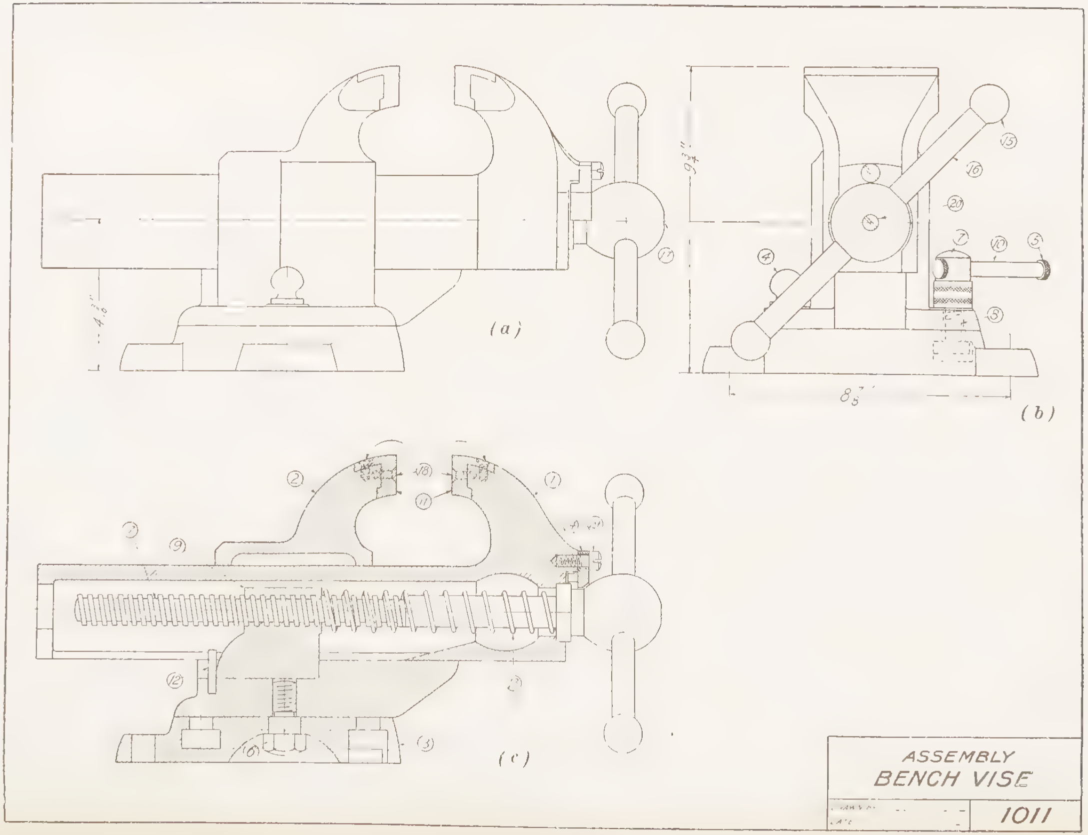


Fig. 67

understanding will then be had of the parts constituting the assembly drawing. Plates 1009 and 1010 may both be sent to the Schools for correction at one time, or separately, as the student prefers.

A general idea of the external appearance of the vise may be had from the perspective view, Fig. 66; the internal construction is indicated in the sectional assembly view, Fig. 67 (*c*), and the perspective longitudinal section, Fig. 68. In Fig. 67, the numbers in the circles are those given to the various parts in the material list on Plates 1009 and 1010.

The vise consists of the front jaw **1** that works through an opening in the back jaw **2**. Motion is imparted to jaw **1** by

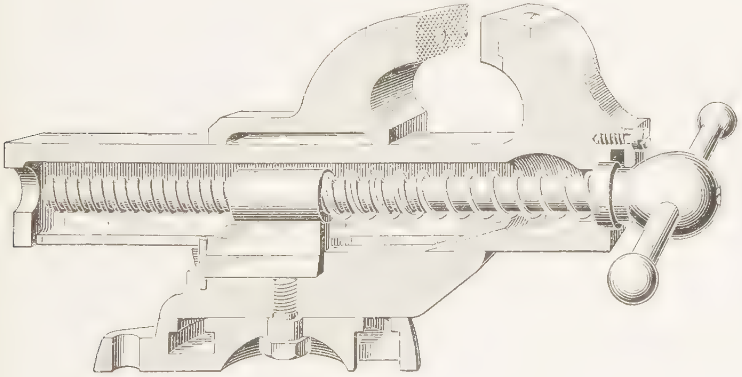


FIG. 68

means of the screw **17**, located inside part **1**, which is cored out for this purpose. The screw engages the nut **9**, which lies in a groove in part **2**, where it is held in position by means of the pin **12**. When an outward motion is given to the jaw **1** by turning screw **17** to the left, the jaw is assisted in its motion by the expanding spring **13**, while the screw is held in position, relative to the jaw, by the guard **14**. Both jaws are provided with steel facings **11**, secured by screws **18**.

The back jaw **2** rests on the base **3**, to which it is clamped by bolt **6** in such a manner as to leave it free to swing around the latter. A sleeve nut **7** engages with a clamping bolt **8**, whose head is held in a circular T-shaped groove in the base.

A loosening of the nut by means of handle **10** allows the whole vise to be swung into any position desired, in which it may be retained by tightening the nut **7**. This clamping device is clearly shown in view (*b*). The advantage of this arrangement is that it enables the workman to turn any side of the work in the vise to the front without having to rearrange it in the jaws. The purpose of pin **4**, shown in position in Fig. 67 (*b*) and also shown in Fig. 69, is to fill a hole which is provided so that the clamping bolt **8** may be used on either the left- or the right-hand side of the back jaw. If this hole were left open, filings and dirt would get into the **T**-shaped groove and clog it.

130. Begin by drawing the front jaw **1** on Plate 1009, shown in four views: a side elevation, an end elevation, a plan, and a section taken on line *A B* of the side elevation. Lay off the horizontal center line, common to the two upper views, $3\frac{3}{8}$ inches from the upper border line, and the vertical center line of the end elevation $9\frac{1}{2}$ inches from the left-hand border line. This vertical center line, if produced, will also serve for the sectional view. Another horizontal center line, $5\frac{15}{16}$ inches from the upper border line, will define the positions of the lower views. The side elevation and the plan are shown broken, as there is not room enough to show them to their full length.

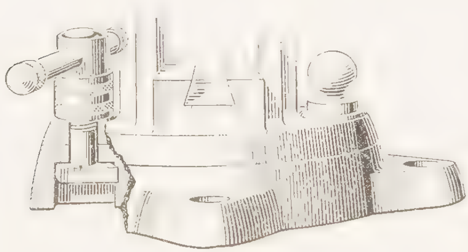


FIG. 69

All the views on this plate are drawn half size; that is, to a scale of 6 inches = 1 foot, except the enlarged detail of the jaw, which is full size.

Draw the end elevation first, then the side elevation, obtaining some of the dimensions in the latter from the first view. The radii of the curves defining the sides of the jaw in the end view and of similar curves found in these drawings are given simply as an aid in constructing them. Ordinarily the deter-

mination of curves of this nature is left to the judgment of the patternmaker, unless there are special reasons why they should be exactly defined. Next draw the plan view, which is a bottom view showing the groove. Some of its dimensions will have to be taken from the side elevation and some from the sectional view, which is to be drawn last. It is seen that the horizontal part of the jaw is cored out along its whole length, and that this cavity is partly rectangular and partly circular in section. The full-size view of the jaw proper, shown in the upper left-hand corner of the plate, will apply to both jaws. Draw the vertical side of the jaw in this view $2\frac{1}{2}$ inches from the left-hand border line, and its upper corner $\frac{3}{4}$ inch below the upper border line.

131. To draw the rear jaw, part **2**, shown in a side and a front elevation, lay off their horizontal center lines $2\frac{5}{8}$ inches from the lower border line, and the vertical center line of the front elevation $8\frac{3}{8}$ inches from the left-hand border line. The extension of the front jaw is to fit the cavity of the rear jaw, but part **1** is made slightly narrower to allow it a freer motion.

It will be observed that the hole in the center of the base is threaded, as is further shown by the note, "Tapped for $\frac{3}{4}''$ bolt." On working drawings, a thread is rarely shown in a hole which is to be tapped; the general rule is to draw two lines at a distance apart equal to the outside diameter of the thread, and to place a note on the drawing stating the size of tap to be used. It has been shown on this plate, however, for the sake of completeness.

132. The base, part **3**, is shown in two views: a plan view and a side view, the latter being half in section and half in elevation. Lay off their vertical center line 3 inches to the left of the right-hand border line, and the horizontal center line for the plan view $2\frac{1}{2}$ inches below the upper border line. Leave a space of $\frac{3}{4}$ inch between the two views. The square hole indicated in the upper part of the plan view serves the purpose of allowing the insertion of the bolt **8** from below into the **T** slot.

133. The parts on Plate 1010 are drawn full size, except those numbered **9**, **13**, **15**, **16**, and **17**, which are drawn half size. Locate the tops of the views in the upper row $1\frac{1}{8}$ inches from the upper border line, and equalize the spaces between them, similar to those on the plate. The curved top line of the nut in part **6** is drawn with a radius of $2\frac{1}{4}$ inches. In drawing the knurled portion of part **7**, draw, first, horizontal lines indicating the upper and lower borders, thereby making sure that the borders will appear even.

The lower part of the nut, part **9**, is dovetailed into the groove situated in the base of part **2**, but this groove is made $\frac{1}{16}$ inch wider to give a certain amount of play to the nut.

134. Draw the center line of the jaw facing, part **11**, $5\frac{3}{4}$ inches below the upper border line, and draw the end view $1\frac{1}{2}$ inches from the left-hand border line, leaving a space of 1 inch between this and the rear elevation. The note "scored face" indicates that the face of the jaw is to be provided with a series of shallow grooves cut at right angles to each other. The appearance of this surface is indicated in Fig. 66. It should be noted that the arcs outlining the upper and lower surfaces of this part are not concentric. The center for the arcs of the lower surfaces is found by drawing a line parallel with the face at a distance from it of $\frac{1}{4}$ inch, then, with a radius of $1\frac{1}{2}$ inches and the lower edge of the face as a center, draw an arc intersecting the parallel line. The point of intersection is the center of these arcs. The center of the upper arcs is found if the vertical line, indicating the face, is produced and intersected by an arc having a radius of $3\frac{1}{4}$ inches, and its center in the upper edge of the face.

135. The horizontal center line for the two views of the handle, part **10**, is located $6\frac{5}{8}$ inches below the upper border line, leaving a space between the end view and the right-hand border line and between the two views, of 1 inch and $\frac{5}{8}$ inch, respectively. The right-hand end of the handle has been drawn in section, to show the threaded hole. In the free space above these views, locate the views of parts **8**, **12**, and **13**. The method of drawing the spring, part **13**, is clearly indicated in

Fig. 70. On the plate only six turns are shown with a break in one of the coils. These six turns are spaced off in a distance of 2 inches.

136. Draw the horizontal center lines of parts **16** and **17**, $1\frac{3}{8}$ inches and $3\frac{7}{8}$ inches, respectively, above the lower border line, and leave a space of $\frac{7}{8}$ inch between them and the left-

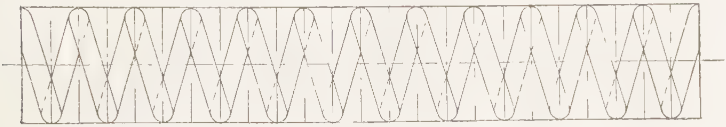
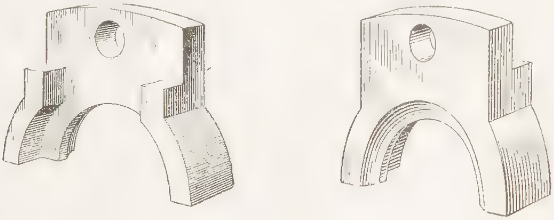


Fig. 70

hand border line. The head of part **17** is not spherical, as the left-hand half is outlined by a semicircle with a radius of $1\frac{1}{4}$ inches, while the right-hand part is outlined by two arcs of $1\frac{7}{8}$ inches radius. . The extreme end of the head is flattened for a distance of $\frac{1}{2}$ inch, corresponding to the diameter of the countersunk part of the hole for screw **20**. The thread on the vise screw is made in a conventional manner, somewhat similar to Fig. 26, *Mechanical Drawing*, Part 1, with the exception that the rear parts of the thread are not shown. Locate the end and side view of part **15** as indicated.

137. Before drawing the guard, part **14**, it should be carefully studied, for its shape is somewhat difficult to ascertain from the three views given. The parts difficult to locate



(*a*) Fig. 71 (*b*)

are the two shoulders on the rear surface. These are shown in dotted lines in the elevation, but appear in the lower view as continuations of the sides. The shape of this part will be better understood by examination of Fig. 71, in which view (*a*)

shows the guard as it appears when seen from the rear and view (*b*) as when seen from the front.

Draw their vertical center line $6\frac{3}{4}$ inches from the right-hand border line and locate the base lines of the views $3\frac{1}{4}$ inches and $1\frac{7}{8}$ inches from the lower border line.

The plates are to be finished by putting on all dimensions and lettering. The material list, title, and number of the plate in each case are to be put in the lower right-hand corner.

PLATE 1011, TITLE: ASSEMBLY, BENCH VISE

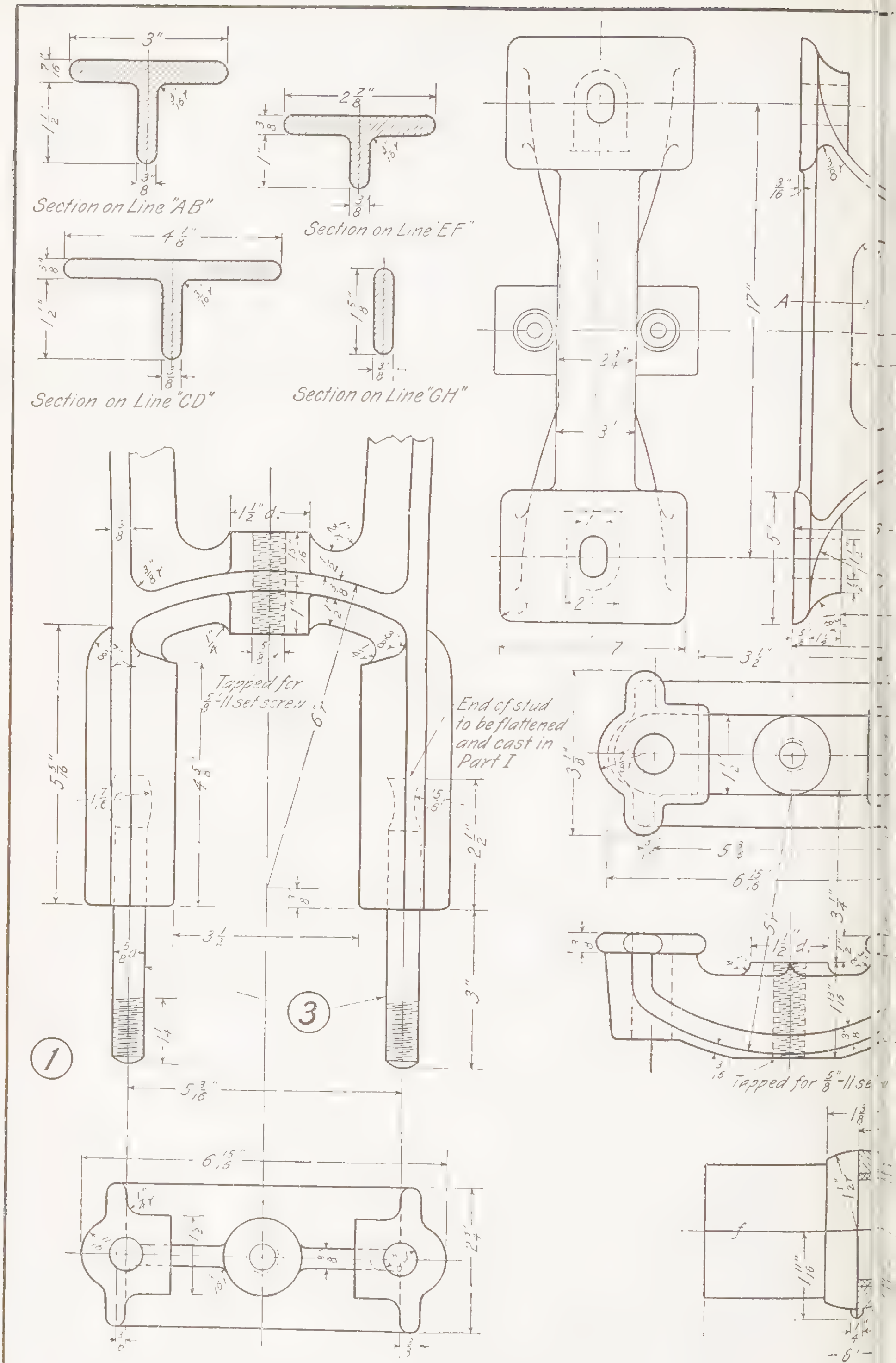
138. Plates 1009 and 1010 being completed, the next to be made is the assembly drawing, which forms Plate 1011. As all the details are given on Plates 1009 and 1010, no specimen plate is furnished in this case, as all the necessary information can be obtained from the detail drawings and Fig. 67. The positions of the details in the assembly views are to be indicated by the reference, or part, numbers enclosed in circles in the usual manner, these numbers, of course, corresponding to those given in the material lists on Plates 1009 and 1010. The plate is to be drawn to a scale of 6 inches = 1 foot.

To draw the assembly views, Fig. 67, locate the horizontal center line of the upper views $3\frac{1}{2}$ inches below the upper border line, and leave a space of $\frac{1}{2}$ inch between these views and their adjacent vertical border line. The lower view should be $3\frac{3}{8}$ inches above the lower border line, and a space of $\frac{1}{2}$ inch should be left between it and the left-hand border line.

Insert the reference numbers at their respective parts, and place the title in the lower right-hand corner as indicated.

PLATE 1012, TITLE: SHAFT HANGER

139. In connection with Plate 1006 it was shown that shafts must be supported in bearings, and also how the bearings may be made to maintain alinement of the shaft. It was explained how shafts may be used to convey motion from one point to another, as, for instance, from an engine to the various machines to be driven by it. Such long shafts—with



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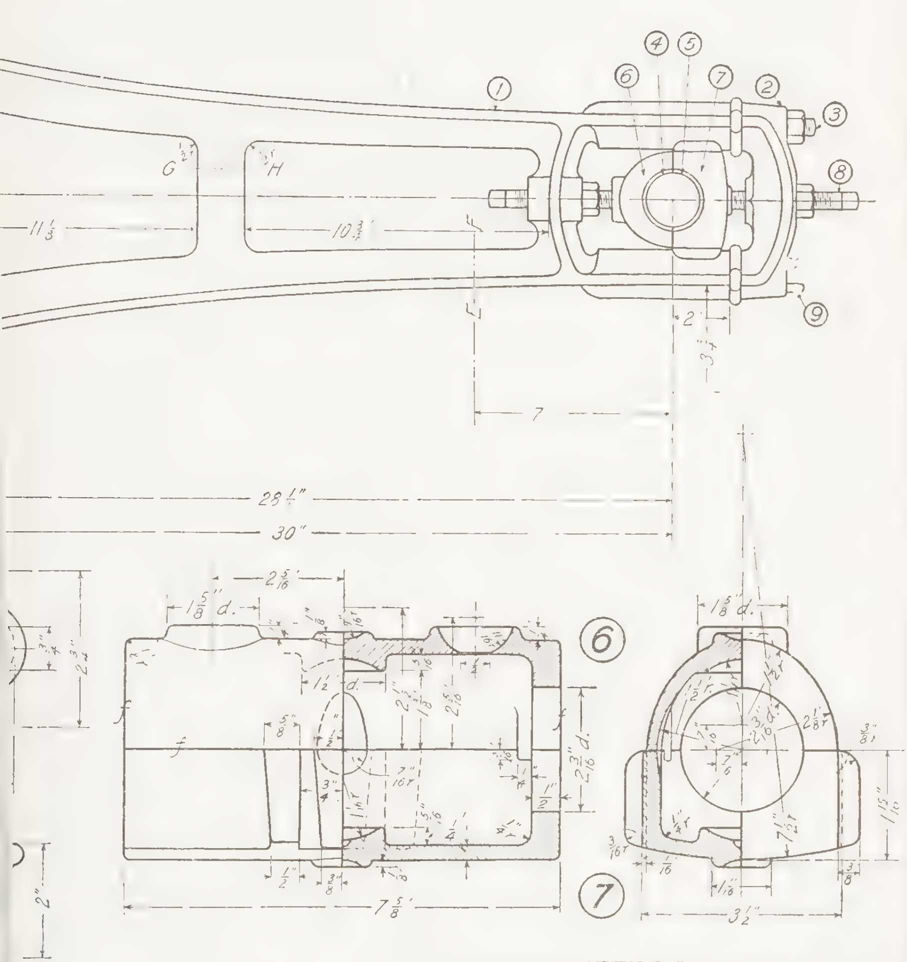

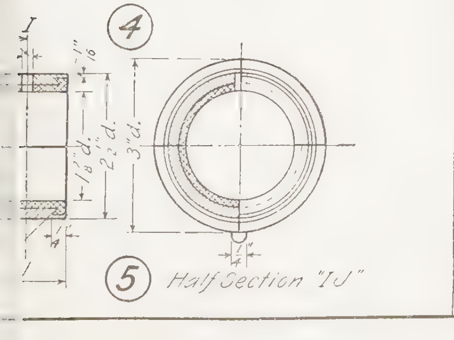

4	3/8 Hexnuts for parts 3+8	9	Machine steel		
2	3/8 set screw 4 long for 1+2	8	Machine steel		
1	Sleeve (Bottom Half)	7	Cast iron	Pattern	F
1	Sleeve (Top Half)	6	Cast iron	Pattern	E
1	Bearing (Bottom Half)	5	Cast iron & babbit	Pattern	D
1	Bearing (Top Half)	4	Cast iron & babbit	Pattern	C
2	5/8 stud 12 long for 1	3	Machine steel		
1	Cap	2	Cast iron	Pattern	B
1	Hanger	1	Cast iron	Pattern	A

SHAFT HANGER

DRAWN BY ....

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their couplings, if any are used—are called *line shafting*. They may be supported on the floor or from the ceiling of the building in which they are placed. In the latter case the supports

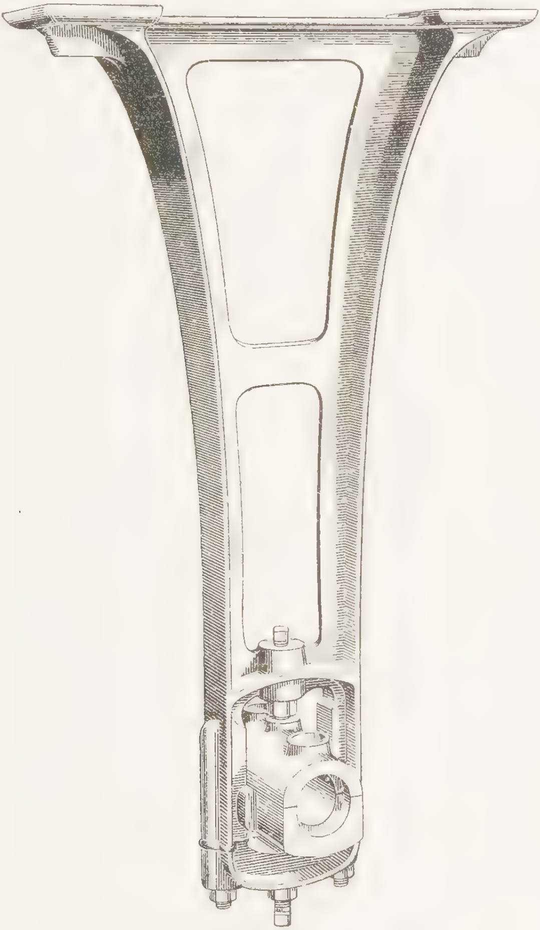

Fig. 72

are called **hangers**, and contain the bearings proper, which may easily be alined. This plate shows a drawing of a common form of such shaft hangers, which is also illustrated in Fig. 72 As the material list shows, it consists of nine parts,

some of which occur but once, others twice, and one four times in the construction, so that the structure consists of fourteen parts, counting every single piece by itself. The part numbered **1** on the drawing is the hanger proper, which is fastened to the ceiling by strong bolts passing through holes in the base. Extending downwards, this hanger terminates in a square-shaped frame open at the lower end, in which is placed a *shell* made in halves, parts **6** and **7** on the plate. Within this shell is located the bearing proper, numbered **4** and **5**, also made in halves. The before-mentioned square-shaped frame is closed, after the shell with the bearing is inserted, by a *cap*, part **2**, secured by two studs, part **3**, and nuts, part **9**. The studs are cast into the hanger, first having been flattened at the end, as directed by the note near the detail of the hanger. Two setscrews, part **8**, serve to adjust the shell containing the bearing proper to correct alinement with the other hangers used to support the same line of shafting. The whole structure put together appears as shown in the perspective view in Fig. 72. It will be noticed that there are very few finish marks on the drawing on the plate, from which it is plainly evident that a large portion of the dimensions are for the foundry, and that there is very little machine finish. The bearing proper, parts **4** and **5**, and the shell, **6** and **7**, are finished where they join together, parts **6** and **7** being also faced off at the ends. Parts **1** and **2** are drilled and tapped for the $\frac{5}{8}''$—11 setscrews used to adjust the height of the bearing, and oil holes are drilled in part **4**. With these exceptions there is no machine work to be done on the hanger. Parts **4** and **5** are lined with Babbitt, the same process being followed as that described in connection with the bearing shown in Plate 1006, although the absence of finish marks indicates that the bearing is not to be bored.

140. All the parts are drawn on the plate in detail, by themselves, except the setscrews, the nuts, and the main frame or hanger proper; these are shown only in the assembly drawing.

The dimensions given on the assembly are leading dimensions only, the few detail dimensions of the main frame given

and placed near the foot being added because the size of the sheet did not permit the portion of part **1** being shown in detail in any other position. The other dimensions of the main frame, or part **1**, are given in the two views located in the lower left-hand corner of the plate.

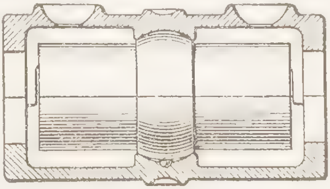

FIG. 73

141. All the details are to be drawn first, and to a scale of 6 inches = 1 foot. Begin with the bearing proper, parts **4** and **5**. This piece is in many respects similar to the one drawn on Plate 1006. There are these differences, however: In the present case the bearing consists of two parts, while the former was one piece only. The present bearing is not self-oiling, so that there are no slots for oil rings, little oil holes being provided instead. The means for preventing the bearing from turning in its seat is in the present case a small boss, or teat, at the bottom of the rounded central portion, which is also called the *ball*. This small teat fits into a recess provided for it at the bottom of the lower shell, part **7**. Fig. 73 shows the appearance of the bearing when placed in its proper position in the shell. For convenience the two halves of the bearing are drawn together, the finish mark *f* placed on the dividing line indicating that both surfaces are to be finished. Both halves are shown half in section. With the instruction given for the similar piece on Plate 1006, there should be no difficulty in drawing the bearing. Place the center lines $1\frac{1}{2}$ inches from the bottom border line, and the vertical center lines $8\frac{7}{8}$ inches and $5\frac{7}{8}$ inches from the right-hand border line, respectively.

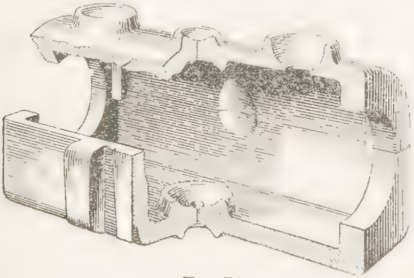

FIG. 74

142. The shells **6** and **7** are drawn in much the same manner as the bearing. The two halves are also shown together,

as were those of the bearing; they are also shown in a perspective view, Fig. 74, partly broken away. Fig. 75 is the same as the views on the plate, except that the lines are all full lines and various parts are lettered to make plain the references in the following instructions.

Draw the horizontal center lines $5\frac{1}{8}$ inches from lower border line, and draw the vertical center lines 5 inches and $1\frac{1}{2}$ inches from right-hand border line, respectively. In the right-hand, or end, view, draw first the circular opening from the center o (see Fig. 75). Next draw the outline of the shell, which is dome-shaped in the upper half and box-shaped in the lower

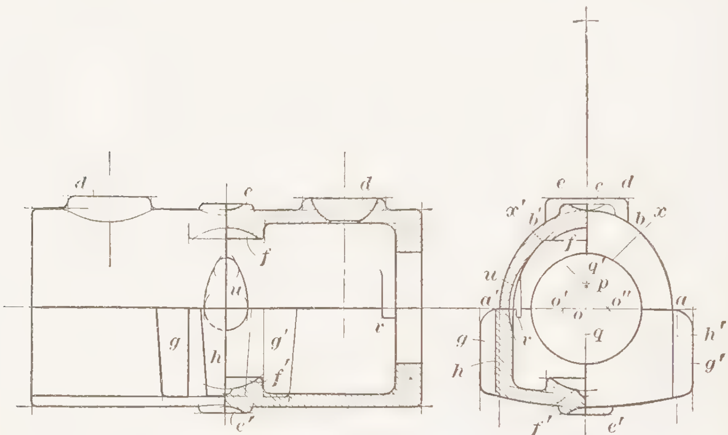

Fig. 75

half. The outline of the upper half is composed of circular arcs of different radii, one drawn with a radius of $2\frac{1}{8}$ inches from a center o' located $\frac{7}{16}$ inch from o on the horizontal center line; the other with p on the vertical center line as a center, $\frac{7}{16}$ inch from o, with a radius of $1\frac{1}{2}$ inches. Lay off o' and p first. Draw a line $o'\,p$ and prolong it, say, to x. When curves of different radii are joined together, as in this instance, their point of junction should lie on a line passing through the centers of the arcs, such as line $o'\,x$. Draw one arc from a till it intersects $o'\,x$ at b; then draw the other arc $a'\,b'$. With p as a center and a radius of $1\frac{1}{2}$ inches describe the arc $b'\,b$.

On top of the upper shell place the boss for the oil cup *d*; the diameter of this is $1\frac{5}{8}$ inches and its top line is $\frac{1}{4}$ inch above the crown of the shell, as seen in the other view. The boss is cupped, the cup having a radius of $\frac{11}{16}$ inch and being $\frac{1}{2}$ inch deep. Next add, in similar manner, the boss *e* for the end of the setscrew to bear against, $1\frac{1}{16}$ inches in diameter and $\frac{1}{4}$ inch high. This boss is also cupped, the cup having a radius of $\frac{9}{16}$ inch and being $\frac{1}{8}$ inch deep. This cup is not visible in the right-hand half of the end view, as the whole boss is hidden by the oil-cup boss and must be shown in dotted lines.

The outline of the lower, box-shaped half of the shell is now to be drawn. Carry straight lines down from *a* and *a′*, one full and one dotted, as shown, the surface represented by the latter being hidden by a projecting lug. The bottom line of the lower shell is a circular arc having a radius of $7\frac{1}{2}$ inches. Its center is obtained by laying out the bottom point $1\frac{15}{16}$ inches below the horizontal center line, and taking the center $7\frac{1}{2}$ inches above on the vertical center line. Draw the boss *e′* at the bottom. The lower shell has on each side three projections *g*, *g′* and *h*, the lugs *g* and *g′* protruding $\frac{3}{8}$ inch, and the raised surface *h* only $\frac{1}{16}$ inch. The outlines of the lugs appear in the end view in full, in both halves of the figure, while the raised surface *h* appears as a full line on the sectional, or left, side and as a dotted line on the right side, being there hidden by the lug *g′*. Round off the lugs with the proper radii. The projecting lugs *g g′* just drawn, together with the raised surfaces *h*, hold the shell in proper position in the main frame, keeping it from moving endwise and sidewise, respectively.

Next define the thickness of the shell in the left-hand side of the figure by drawing concentric arcs and lines parallel to the outlines already drawn. The thickness of the shell is $\frac{1}{4}$ inch, as given in the other view at the bottom, it being understood that the general thickness of shell is the same throughout. On the inside of the shells are placed bosses *f* and *f′*, cupped to receive the ball, or rounded middle, portion of the bearing. These cups have, however, a smaller radius than the ball, for the following reason: As has been said, these surfaces are not finished. It would, therefore, not be practical to cast them

so as to make them exactly coincide. By making the cups of smaller radius, the surfaces will be in contact only at the rim of the cup, as shown in Fig. 76. The radii of the cups are given as $1\frac{1}{16}$ inches; to find their centers, q and q', proceed as follows: With o as a center draw a circle with a radius of $1\frac{1}{2}$ inches, as shown in Fig. 76; next lay off $1\frac{3}{8}$ inches from o downwards along the vertical center line, and draw a horizontal line $r\,s$ marking the top of the cupped boss. With the point of intersection t as a center and a radius of $1\frac{1}{16}$ inches, strike an arc cutting the vertical center line at q; with q as a center, draw the arc defining the bottom of the cup. Draw the upper cup in the same manner. Draw the little recess in the lower cup for the teat referred to in Art. **141.** The thickness of the shell is changed at two other places, namely, at u, Fig. 75, and at the corresponding point opposite, being recessed $\frac{1}{16}$ inch deep and $\frac{7}{8}$ inch wide to accommodate the ball, as the shell is only $2\frac{7}{8}$ inches wide in the clear, while the ball is 3 inches in diameter. The top sleeve, part **6**, is held in position, in relation to bottom sleeve, part **7**, by four projections v, one placed at each corner of the top half and slipping into the bottom half.

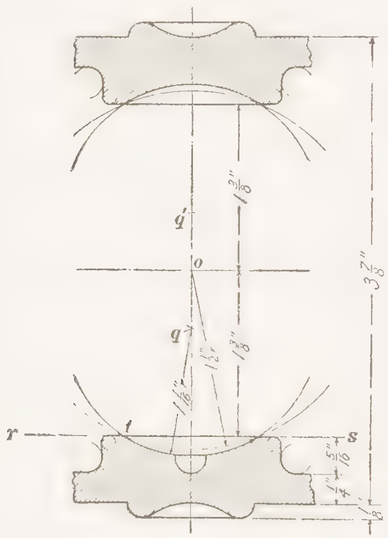

Fig. 76

143. The other view is now easily drawn. Carry over from the end view horizontal lines limiting the inside and the outside of the shell, the tops and bottoms of the bosses for the oil cups and ball cups, keeping in mind the fact that the line representing the inside of the top of part **6** is not found by projecting horizontally from the end view, as the top point

there represents the bottom point of the cup *f*. The inside top line in the side view must be found by laying off a point $\frac{1}{4}$ inch below the outside of the shell, and through this drawing a horizontal. Lay off the center lines and centers of the oil cups and draw their outlines. Carry over the centers of the ball cups and draw their outlines, also those of the set-screw cups. Lay out the lugs *g* and *g'*, the raised surface *h*, the recess *u*, and the projections *v*, the latter visible only in the right-hand or sectional half of the figure. Round off the corners and draw the fillets. The outlines of the recess *u* in the side elevation are found by ascertaining the intersection between the ball of the bearing and the inside of the shell. In this case it is not required that the intersecting points be determined by means of projection, but an approximate curve may be drawn in the following manner: With the intersecting point of the two center lines as a center, draw an arc with a radius of $\frac{7}{16}$ inch. Lay off another center $\frac{3}{4}$ inch above the first and draw another arc with a radius of $\frac{1}{4}$ inch. By means of the irregular curve draw two curves tangential to the two arcs.

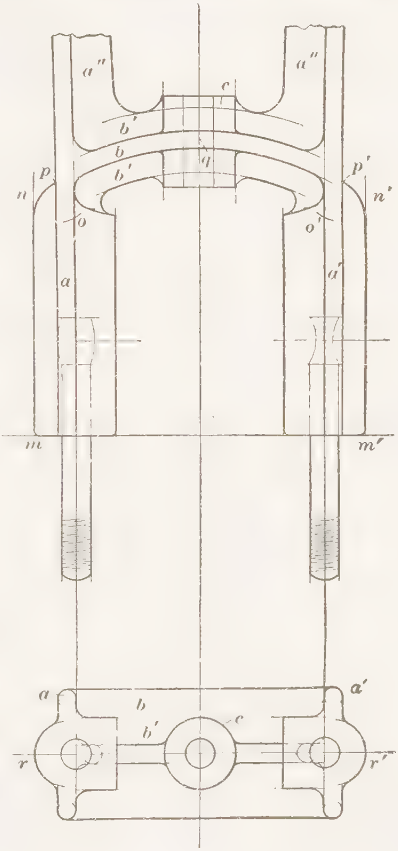

FIG. 77

144. Now draw the detail numbered 1 and 3 (see also Fig. 77), which is the lower portion of the main frame, with

its bolts cast into it. It will be noticed that the detail drawing of parts **1** and **3** shows only a portion of the frame, and that it is drawn to a larger scale than the frame shown in the assembly drawing. This is another illustration of the practice referred to in the description of the enlarged cross section of the pulley rim, Plate 1005. The size of the plate would not permit of drawing the entire frame to the scale used for the details; hence, the upper part only is shown, drawn to the enlarged scale, the dimensions necessary for the foot of the frame being given on the assembly. Commence with the top view or elevation. Draw a vertical center line $2\frac{7}{16}$ inches from left-hand border line. Draw parallel to it the center lines of the bolts $5\frac{3}{16}'' \div 2 = 2\frac{19}{32}$ inches from it, on either side. Draw a horizontal line $m\,m'$, Fig. 77, which determines the bottom, and is $4\frac{1}{2}$ inches (actual measurement) from the lower border line. Lay out the inside and outside dimensions ($3\frac{1}{2}$ inches and $6\frac{15}{16}$ inches) of the uprights and draw their vertical outlines $m\,n$, $m'\,n'$. The uprights have ribs a and a', the inside edges of which coincide with the center lines of the bolts; the ribs are $\frac{3}{8}$ inch thick. These ribs extend to the upper part of the frame, while the thick parts of the uprights terminate on the outside in caps which are partly spherical and have a radius of $\frac{7}{8}$ inch, with centers on the inside edges of the ribs. To locate these centers, lay off from $m\,m'$ the height $5\frac{5}{16}$ inches on the outside edges of the ribs to p and p'; with these points as centers cut the inside edge line of the ribs with arcs struck with a radius of $\frac{7}{8}$ inch, obtaining centers o and o' of the caps. A ribbed bridge $b\,b'$, having a cylindrical boss c in the center for the setscrew, connects the two uprights. This bridge is curved to a circular arc, the upper edge of the central horizontal rib b having a 6-inch radius, whose center is located $\frac{3}{8}$ inch from the line $m\,m'$. The lower edge of the central rib b is $\frac{3}{8}$ inch away from the upper, and is struck from the same center. The remainder of the bridge should be readily drawn. Draw the cylindrical boss c by locating a point q in the middle of the rib b and laying off points $\frac{3}{4}$ inch to the right and left of the vertical center line, and $\frac{15}{16}$ inch above and 1 inch below point q. Now put in the fillets joining the various parts, and

round off the corners. Next draw in the hole for the setscrew in the boss *c*, and finally the studs 3. The flattening of the studs is shown in a conventional manner without dimensions, this being safely left to the blacksmith.

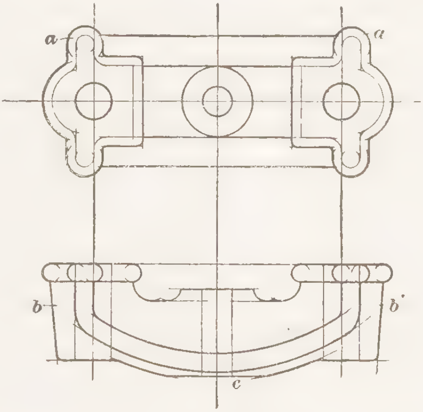

FIG. 78

Begin now with the bottom view. Carry down vertically the center lines of the studs, having previously drawn a horizontal center line of the whole figure $1\frac{3}{16}$ inches (actual measurement) from the lower border line. Draw the circles representing the studs, the threaded setscrew hole, and the cylindrical boss *c*. Carry down the outside edges *m n* and *m′ n′* of the uprights from the upper figure to the lower, intersecting the horizontal center line in *r* and *r′*, through which points draw arcs of circles with a $\frac{11}{16}$-inch radius to represent the plan of the uprights. Carry down the inside edges of the uprights and lay off their width, which is $1\frac{1}{2}$ inches. Carry down the edges of the ribs *a* and *a′* and make their width $2\frac{3}{4}$ inches. Finally, draw the rib *b′*, $\frac{3}{8}$ inch thick. Round off corners and put in fillets.

145. The next part to be drawn is the cap, part 2, also shown in Fig. 78 and in the perspective view in Fig. 79. Draw center lines $7\frac{3}{8}$ inches from the left-hand border line and 6 inches from the bottom border line, respectively. It is best to begin with the upper view, or plan. Establish the stud-hole centers; draw the circles representing the stud holes, the setscrew boss, and the setscrew hole. Lay out the outside and inside dimensions

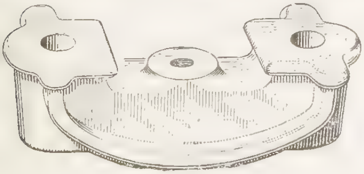
FIG. 79

of the body and rib of the cap as well as their width; the dimensions $6\frac{15}{16}$ inches, $3\frac{1}{2}$ inches, $2\frac{3}{4}$ inches, and $1\frac{1}{2}$ inches will be found to be the same as the corresponding dimensions of the uprights of part **1**. These outlines will be partly dotted lines, being hidden by a half-round molding *a a* $\frac{3}{8}$ inch wide carried all around. In the plan, this molding shows in parallel lines and concentric circles to the outlines of the body proper and $\frac{3}{16}$ inch away from them. Now draw the lower view or elevation. It is drawn in a manner similar to the bridge portion in part **1**. Notice that the body tapers on the sides *b* and *b′* and that it is flattened at the bottom at *c* for the nut of the setscrew. Put in circles for fillets and round off the corners with proper radii.

146. All that now remains to be drawn is the assembly shown in two views and in four sections through the frame and web. The assembly views, which are a plan and an elevation, are drawn to a scale of 3 inches = 1 foot. Begin by drawing the elevation. Draw the center line *n n′*, Fig. 80, 3 inches from the upper border line, and a base line *a b* $7\frac{3}{8}$ inches from the left-hand border line; draw center lines *q r* and *s t* for the bolt holes; lay out the thickness of the base and of the bosses *e* and *e′*, and draw in the bolt holes. The lower edge of the rib *d* is parallel to the base line; the rib itself is $1\frac{1}{2}$ inches high, as indicated on the section along *A B* shown at the left-hand upper corner of the plate. Lay off 30 inches from the base line to locate the center of the shaft; this distance is called the *drop* of the hanger. Draw a center line through *o* perpendicular to *n n′*, and complete this end of the hanger from dimensions on the details previously drawn. The curve of the side of the hanger is partly that of an ellipse, the half diameters of which are $3\frac{3}{4}$ inches and $28\frac{1}{8}$ inches. Use for its construction the first of the two methods given in *Geometrical Drawing*, in the manner shown in Fig. 80. From *u* to *z* the curve is a circular arc tangent to the ellipse at *u* and to the bottom of the base at *z*, and passing through the end *y* of the long diameter of the ellipse. If the circles used for the construction of the ellipse are divided into the same number of equal parts as shown in the illustration, then the point *u* is located at the end of the third

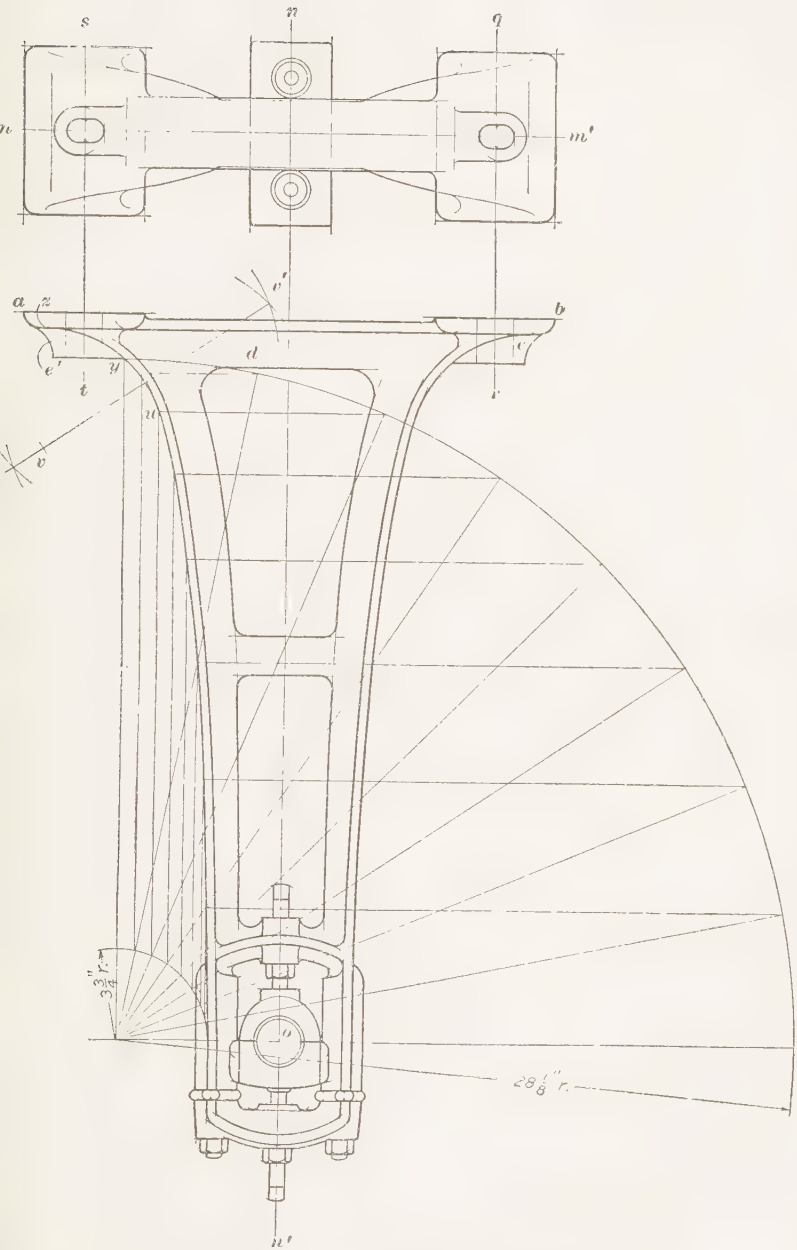

FIG. 80

line from the left in Fig. 80. The center from which to describe the arc $u\,z$ may be found in the following manner. Draw a straight line connecting u and y and bisect this line by a perpendicular $v\,v'$ in the manner described in *Geometrical Drawing*. Then, with a center on the line $v\,v'$ and with a suitable radius, draw the arc $u\,y$ and continue it till it intersects the lower side of the base in point z. The other construction dimensions can be obtained from the cross-sections and the over-all dimensions given on the assembly. The bottom plan to the left of the figure just drawn is made by drawing the center line $m\,m'$, Fig. 80, $5\frac{1}{2}$ inches from the left-hand border line, carrying over horizontally all dimensions from the elevation that can be so obtained, and laying off the others from the center line $m\,m'$.

The irregular curves in this view, which represent parts of the outlines of the sides of the hanger, may be drawn in approximately, as shown in the drawing plate; but if it is desired to construct them, a side view will be necessary. Such a view (shown in Fig. 81) can be constructed from the sections on $A\,B$, $C\,D$, $E\,F$, and $G\,H$ given on the plate. Then, in the manner shown in Fig. 81, suitable points can be projected from this side view to intersect the curved lines of the frame in the elevation. These points of intersection can then be projected to the plan view above, and the width of the frame can be transferred at each point.

Finally draw the four sections of the main frame at the left-hand upper corner of the plate. There should be no difficulty with these.

In lettering the material list, note that part **8** is called for twice, it being plainly evident from the assembly that two adjusting screws are necessary, and also that four hexagonal nuts, part **9**, are required for parts **8** and **3**. Six patterns are called for to complete the hanger, although part **4** could be produced from pattern D, which is made for part **5**. It is probable, however, that of standard parts of this sort large numbers will be made, and it is therefore advisable to call for patterns for each part.

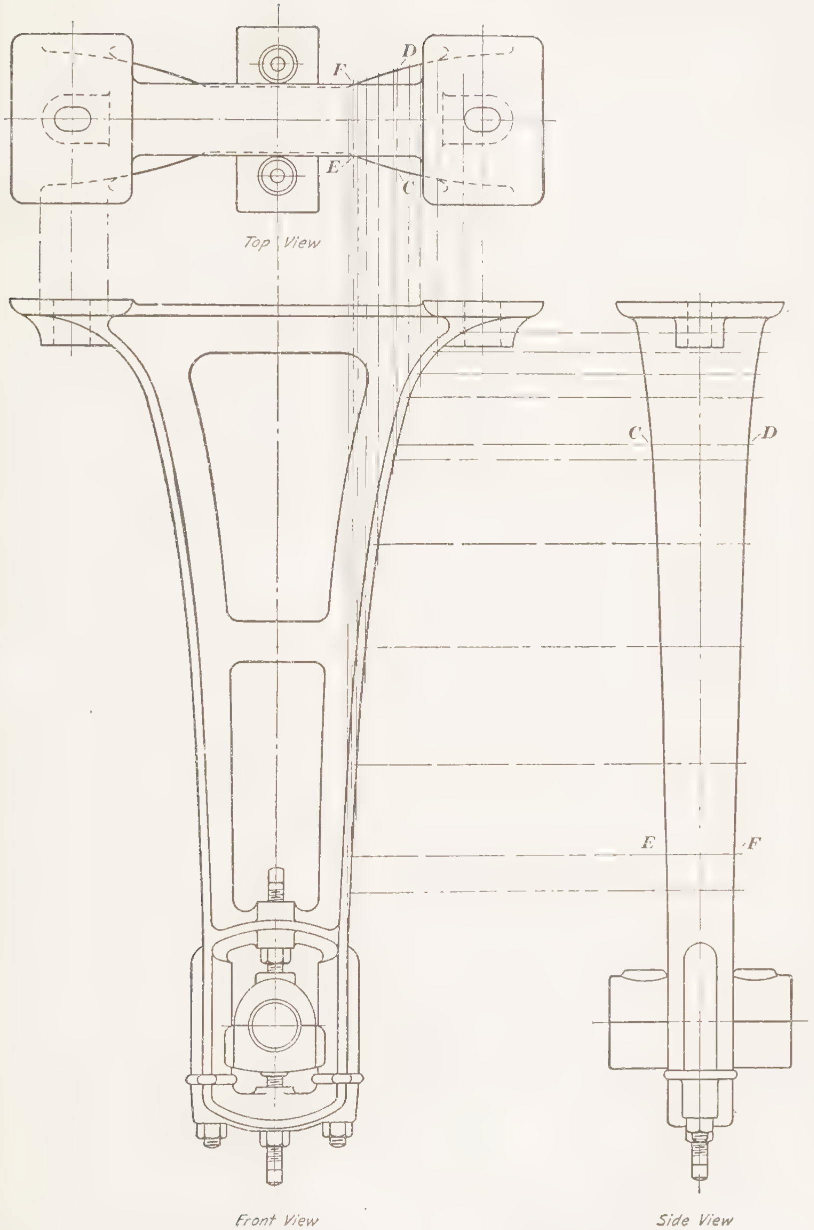

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FIG. 81

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PLATE 1013, TITLE: GEAR-TEETH PROFILES

147. The style of drawing shown in Plate 1013 is of a diagrammatic nature, its purpose being to show the theory and construction of gear-teeth in general, while Plates 1014 and 1015 are drawings of two common types of gear-wheels. This plate is drawn full size.

148. The Cycloid.—If a circle is rolled on a straight line without sliding, a point on the circumference of the circle will describe a curve called a *cycloid*. The circle is called the *generating circle*. The shape of the curve and the manner of drawing it are shown in Fig. 1 on the plate. Let O be the center of the generating circle, which is $1\frac{3}{4}$ inches in diameter, P the point on the circumference of the generating circle, and $A B$ the straight line on which the generating circle is rolled and which is equal in length to the circumference of the generating circle, or $1\frac{3}{4}'' \times 3.1416 = 5.4978$, say $5\frac{1}{2}$, inches. The generating circle should be so placed that its center O lies over the center of the line $A B$, as shown.

On the plate, locate the point O $1\frac{1}{4}$ inches below the top border line, and $3\frac{3}{8}$ inches from the left-hand border line. Divide the generating circle into any number of equal parts, in this case 12, or $P\ 1$, $1–2$, $2–3$, $3–4$, etc., and through these points draw lines $C D$, $E F$, $G H$, etc., parallel to the line $A B$. Through the center O of the generating circle draw the radius $O\ 6$. Divide the line $A B$ into the same number of equal parts as the generating circle is divided into, as $A\ 1$, $1–2$, $2–3$, etc., and through these points draw lines perpendicular to $A B$ terminating in the line $G H$, as $A G$, $1–1'$, $2–2'$, $3–3'$, etc. From the point $1'$, with a radius equal to the radius of the generating circle, as $O\ 6$ or $1'–1$, describe an arc intersecting the line $K L$ in the point P^1; from the point $2'$, with the same radius, intersect the line $I J$ in the point P^2; from the point $3'$, with the same radius, intersect the line $G H$; continue in a similar manner with the remaining points $4'$, $5'$, $7'$, $8'$, etc., intersecting the lines $E F$ and $C D$ in the points P^4, P^5, P^7, P^8, etc. The points A, P^1, P^2, P^3, etc. are points in the curve through

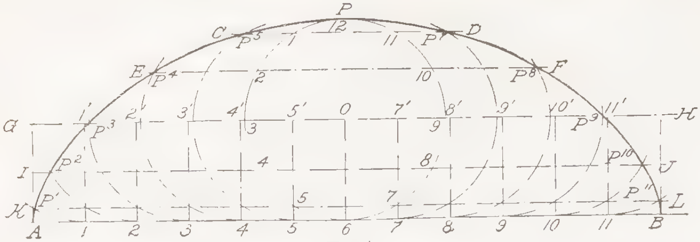


Fig 1

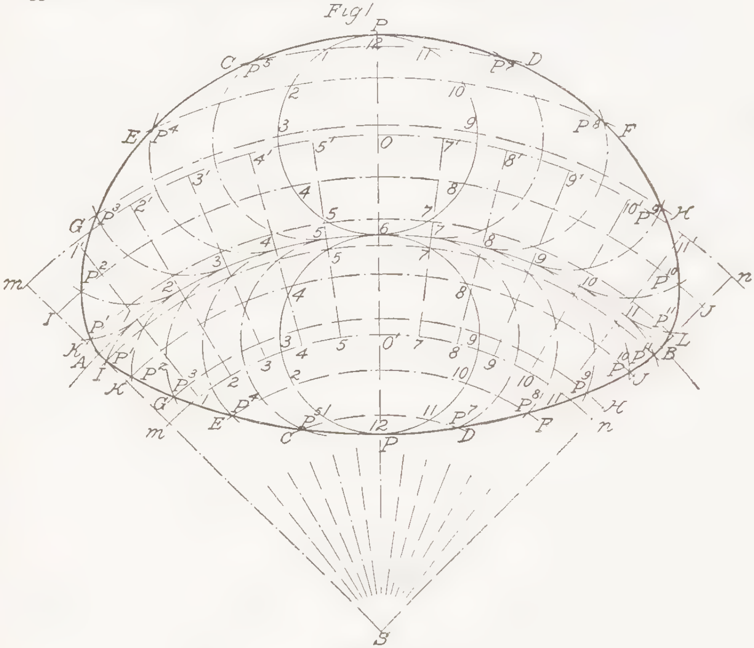


Fig 2.

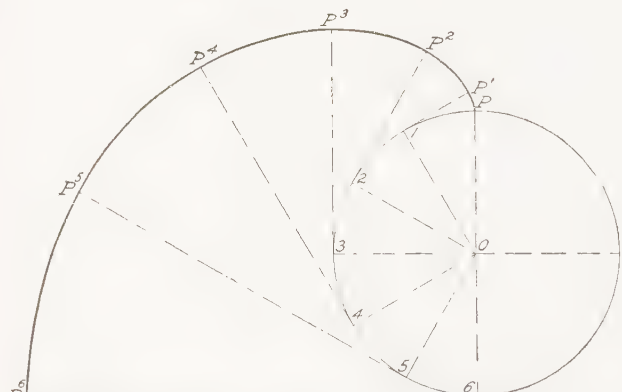


Fig 3.

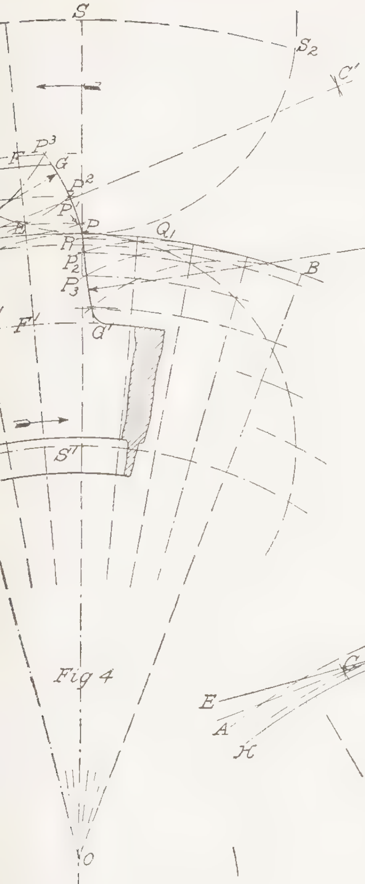
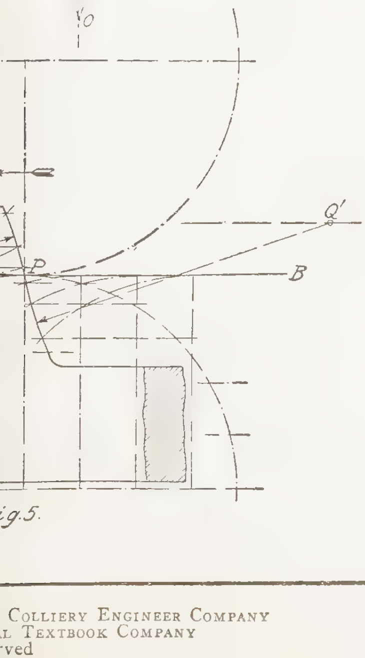


Fig 4



ig.5.

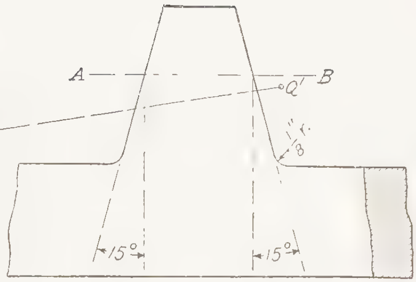


Fig. 7

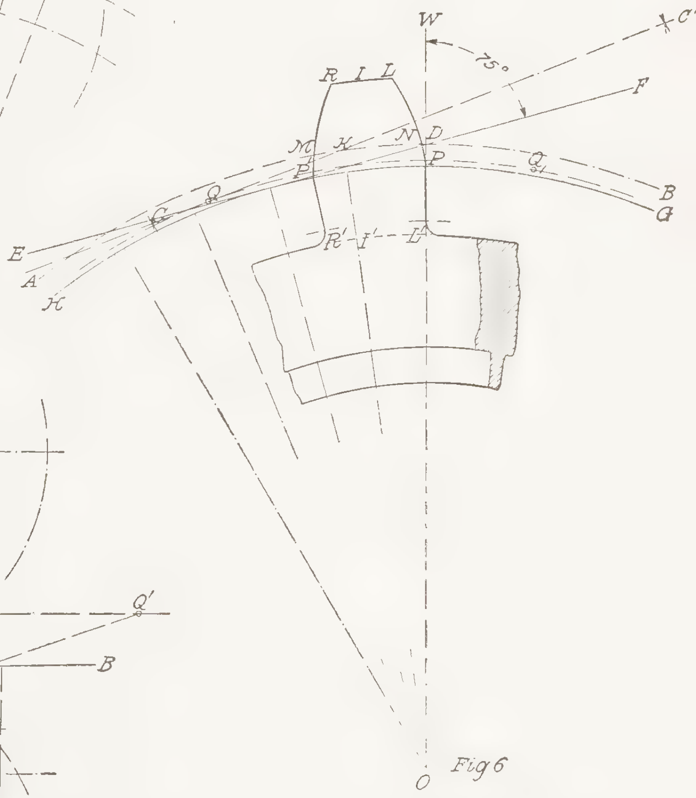


Fig 6

GEAR TEETH PROFILES

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1013

Name, Class Letters, and Number

which the cycloid may be drawn. It will be noticed that when the center O of the generating circle coincides with the point G, the point P on the circumference of the generating circle coincides with the point A; and that when the generating circle is revolved toward the right, without sliding, until the center O coincides with the point $1'$, the point P will coincide with the point P^1. Thus it is seen how the point P passes through all the points from A to B, namely, A, P^1, P^2, P^3, etc., when started at A and revolved toward the right to B.

149. The Epicycloid.—If the generating circle is rolled, without sliding, on the outside of the circumference of an arc of a circle supposed to be at rest, instead of being rolled on a straight line, the curve described by a point P of the generating circle will be an *epicycloid*.

The manner of drawing such a curve is shown in Fig. 2. A *6* B is the arc upon which the generating circle is rolled, its center being at S and its radius being $3\frac{1}{2}$ inches. Locate the center S $3\frac{7}{8}$ inches from the left-hand border line and $5\frac{1}{8}$ inches from the bottom border line. The diameter of the generating circle is in this case the same as in Fig. 1, or $1\frac{3}{4}$ inches. Make the lengths of the arcs *6* A and *6* B each equal to half the length of the circumference of the generating circle. To do this, first calculate the length of half the circumference of the generating circle. Then, tangent to the arc *6* A at *6*, draw a straight line of a length equal to the half circumference just found, and make the arc *6* A equal to it in length by means of the approximate method given in *Geometrical Drawing*, Part 2, Problem 20. The arc *6* B is of like length, and the whole arc A *6* B therefore is equal in length to the circumference of the generating circle. Divide the arc A *6* B and also the generating circle into the same number of equal parts, in this case 12, as A *1*, *1–2*, *2–3*, etc., and P *1*, *1–2*, *2–3*, etc., and draw radii from the center S to the points of division on the arc A *6* B. During the revolution of the generating circle, the center O will describe an arc $m\ O\ n$ concentric with the arc A *6* B and having the same number of degrees in it as A *6* B. Produce the radii just drawn to the arc of center positions $m\ O\ n$.

intersecting this arc in the points m, $1'$, $2'$, $3'$, $4'$, etc. Through the points of equal divisions, 1, 2, 3, etc., of the generating circle describe concentric arcs having the center S, as CD, EF, GH, IJ, and KL. With the points $1'$, $2'$, $3'$, $4'$, etc. as centers and radii equal to the radius of the generating circle describe arcs cutting the arcs KL, IJ, GH, etc. in the points P^1, P^2, P^3, etc., which are points on the epicycloid.

150. The Hypocycloid.—When the generating circle rolls on the inside of the arc, as in the lower part of Fig. **2**, the curve described by a point on the circumference is called a *hypocycloid*. The method of drawing it is similar in all respects to that just given for the epicycloid and it should be possible to construct it from the drawing without further explanation. The diameter of the generating circle is $1\frac{3}{4}$ inches as before.

151. The Involute.—Suppose that a string is wound on a cylinder and that, when wound up, the outer end of the string is at the point P in Fig. **3**. If this string is unwound from the cylinder, keeping it constantly tight, the end P will describe a curve known as the *involute of the circle*, or, more simply, the *involute*. To construct such a curve geometrically, let O be the center of the given circle representing the cylinder, which, in Fig. **3**, is $2\frac{1}{2}$ inches in diameter, and P the free end of the string when wound on the cylinder. Locate point O $4\frac{1}{2}$ inches from the left-hand border line and $2\frac{3}{8}$ inches above the bottom border line. Divide one-half of the given circle into any number of equal parts, in this case 6, as $P\,1$, 1–2, 2-3, etc., and through each of these points draw tangents to the circle, as P^1, P^2, P^3, etc. To draw these tangents, first draw the radii $O\,1$, $O\,2$, $O\,3$, etc. and then draw the tangents $1\,P^1$, $2\,P^2$, $3\,P^3$, etc. at right angles to them. By means of the approximate method given in *Geometrical Drawing*, Part 2, Problem 21, find the length of the arc $1\,P$ and make the length of the tangent $1\,P^1$ equal to this length; of the tangent $2\,P^2$ equal to twice this length; of the tangent $3\,P^3$ equal to three times this length, and so on. The curve drawn through the points P^1, P^2, P^3, P^4, etc. will be the required involute. The use of these curves will now be explained.

152. Terms Applied to Gearing.—On Plate 1014, in Fig. **1**, is shown one-half of two spur gear-wheels in mesh. The two dash-and-dot circles tangent to each other at P are struck from the centers of the gear-wheels and are called the *pitch circles*. The diameter of any gear-wheel is always understood to be the diameter of its pitch circle unless it is specified as *diameter at root*, or *diameter over all*. The length of that part of the pitch circle between the centers of any two consecutive teeth is called the *circular pitch*, or simply the *pitch*. Thus, in Fig. **1**, Plate 1014, the length of the arc $a\,b$ is equal to the pitch of either gear-wheel. When the gear-wheels are cut in a gear-cutter, the width of the tooth $c\,d$ on the pitch line is equal to the space $d\,f$; that is, the arc $c\,d$ is equal to the arc $d\,f$, and each is equal to half the pitch. When the gear-wheels are cast, that is, when they are not cut in a gear-cutter, clearance is given between the back of one tooth and the front of the tooth following, to allow for inequalities in casting. This clearance, or *backlash*, as it is usually termed, is generally made equal to 4 per cent. of the pitch. This is done by making the thickness of the teeth $c\,d$ equal to .48 of the pitch.

The part $C\,C_1$ of the tooth that lies beyond the pitch circle is called the *addendum*, and the part $C\,C_2$ that lies below it is called the *root*. The *face* of the tooth is the part $C\,C_1C'\,C$, Fig. **2**, of the tooth above the pitch circle, extending the whole width of the tooth. The *flank* is the part $C\,C_2C''\,C$, Fig. **2**, of the tooth below the pitch circle, extending the whole width of the tooth. The terms addendum and root mean distances only, while face and flank mean surfaces.

The usual practice is to make the addendum equal to .3 p, and the root equal to .4 p, where p = circular pitch. The distance $C_1\,C_2$ is called the whole depth of the tooth.

153. Cycloidal Teeth.—The method of describing the curves of teeth shown on the Plate 1013, Fig. **4**, is a convenient way of drawing the *cycloidal*, or *double-curved, teeth*. Cycloidal teeth are constructed by making the outline of the face a part of an epicycloid and the flanks a part of the hypocycloid, hence the name double-curved teeth.

In drawing Fig. 4, let AB be part of a pitch circle struck with a radius of $5\frac{1}{2}$ inches, the center O being $7\frac{1}{2}$ inches from the right-hand border line and 8 inches below the top border line. For convenience in drawing the tooth, let the pitch be 2 inches. With O as a center, which is the center of the gear-wheel, and a radius of $5\frac{1}{2}$ inches, describe the arc AB, part of the pitch circle. Through O draw a straight line OS, cutting AB in P. Make the radius of the generating circles SP and $S'P$ $1\frac{7}{8}$ inches for this case and describe arcs having centers at S and S' on the line OS. With O as center and OS as radius describe the arc $S_2 S_1$. In connection with the gear-wheel teeth, the generating circles are frequently called *describing circles*. Roll the outer describing circle upon AB in such a manner that the center S will move in the direction of the arrow along the arc $S_2 S_1$. By means of the method given in Fig. 2, find the points P^1, P^2, P^3, etc. on the epicycloid described by the point P. Trace a faint curve through the points just found and measure off the thickness of the tooth on the pitch circle, where

$$PD = .48\,p = .48 \times 2'' = .96 \text{ inch}$$

Make EF = the addendum $= .3 \times p = .3 \times 2'' = .6$ inch.

With O as a center and OF as a radius describe an arc cutting the epicycloid in G. Now roll the inner describing circle on AB, so that its center S' moves in the direction of the arrow, and find the points P_1, P_2, P_3, etc. of the hypocycloid described by the point P, through which trace a faint curve. Make EF' equal the flank of the tooth $= .4\,p = .4 \times 2'' = .8$ inch, and with O as a center and OF' as a radius describe an arc cutting the hypocycloid in G'. PG' is the outline of the flank of the tooth and PG that of the face.

154. Approximate Tooth Curves.—Since it would be a tedious operation to draw all the tooth curves in this manner, it is usual to approximate the curves by means of circular arcs; that is, to find by trial a center Q and a radius QP such that an arc described from this center and with this radius will pass through the points on the curve GP and coincide with that curve as closely as possible; also, to do the same with regard to the curve PG', using the center Q' and the radius $Q'P$.

To find the center Q or Q' of these circular arcs proceed as follows: With P and G as centers and any radius, describe arcs intersecting in C and C'. Draw a straight line through C and C'; the center Q must lie on $C C'$ to the left of $G P$. Try different points *1*, *2*, *3*, *4*, etc. on this line as centers and $1 G$, $2 G$, etc. as radii, and see if one of the arcs struck with either one of these centers and radii will coincide with the epicycloidal curve $G P$. Make this circular arc fit the curve for a short distance beyond G—as far as P^3, for example; this will insure the arc being more nearly correct. This should be done in every case when finding an approximate radius of this kind. Continue in this manner until the point Q is found such that an arc struck with Q as a center and $Q G$ or $Q P$ as a radius will coincide as closely as possible with $G P$. If a circle were drawn with O as a center and $O Q$ as a radius, the centers of all the circular arcs of the faces of the teeth would lie in this circle, and the radii of these arcs would be equal in length to $Q P$. Hence, to find the center Q_1 of the arc $D H$ forming the back of the tooth, take D as a center and $Q P$ as a radius and describe a short arc cutting, in Q_1, the circle passing through Q. Then, with Q_1 as a center and the same radius, describe the arc $D H$. In a similar manner find the center Q' and describe $P G'$, also $D H'$. Instead of letting the flank form a sharp corner at the bottom of the tooth, as shown dotted at G', it is usual to put a small fillet there, as shown by the full line. This makes the tooth stronger and less liable to break or to crack in casting. The entire tooth outline or curve $G P G'$ or $H D H'$ is called the *profile* of the tooth.

155. Rack.—As a radius of a circle is increased indefinitely, any arc of the circle approaches more and more to a straight line, and when the radius becomes infinite, the arc becomes a straight line.

A **rack** is a bar provided with teeth whose pitch circle is a straight line; the tops of the teeth all lie in the same plane.

A portion of a rack and one tooth are shown in Fig. 5. Make the pitch the same as before, then the addendum and root are also the same, that is, .6 inch and .8 inch. Make the radius of

the describing circles $1\frac{7}{8}$ inches, as before, and locate the center of the upper describing circle $4\frac{9}{16}$ inches above the bottom border line. It is evident that the tooth profile will be formed of parts of cycloids formed by rolling the describing (generating) circle upon the pitch line $A B$. Draw a small part of the cycloidal curves, as shown in the figure, by the method given in Fig. **1**; lay off the addendum and root and find the approximate radius in the same manner as in the last figure. The centers of the curves for the faces and flanks of all the teeth of the rack will evidently lie on the straight lines passing through Q and Q', respectively, and parallel to the pitch line $A B$.

156. Involute Teeth.—In Fig. **6** is shown the manner of drawing the *involute*, or *single-curve*, *tooth*, and in Fig. 82 the same construction is shown in more detail. The profile in this case is formed of a portion of an involute curve combined with a radial line. The circle from which the involute is constructed is called in this case the *base circle*. To find the base circle, draw the arc $A B$, which is part of the pitch circle, with a radius of $5\frac{1}{2}$ inches and having its center at O. Locate this center $2\frac{3}{4}$ inches from the right-hand border line and $1\frac{3}{4}$ inches above the bottom border line.

Draw any radial line, as $O W$, cutting the arc $A B$ in D. Through D draw the straight line $E F$, making an angle of 75° with $O W$. With O as a center and a radius to be found by trial, draw a circle tangent to $E F$. This circle, of which the arc $H G$ is a part, is the base circle, and cuts $O W$ in P. Upon this circle construct, in exactly the same manner as was shown in Fig. **3**, a portion of an involute curve passing through P.

In Fig. 82 it is clearly shown how the method given in Fig. **3** is applied to this case. Lay off the addendum $I K = .6$ inch, and with O as a center and $O I$ as a radius describe an arc to form the top of the tooth, intersecting the involute in L. That part of the flank below the base circle is straight and is a part of the radius drawn to the point P. $K I'$ is the root. The tooth has a fillet at L' and K', as in cycloidal teeth. A circular arc is passed through the points L and P, coinciding as nearly as possible with the involute curve $L P$. Its center Q is found

in the same manner as in Fig. 4, the application of the method to this particular case being shown in Fig. 82.

The radius for the curve *LP* is found in the following manner: From *L* and *P* with the compass set to any convenient

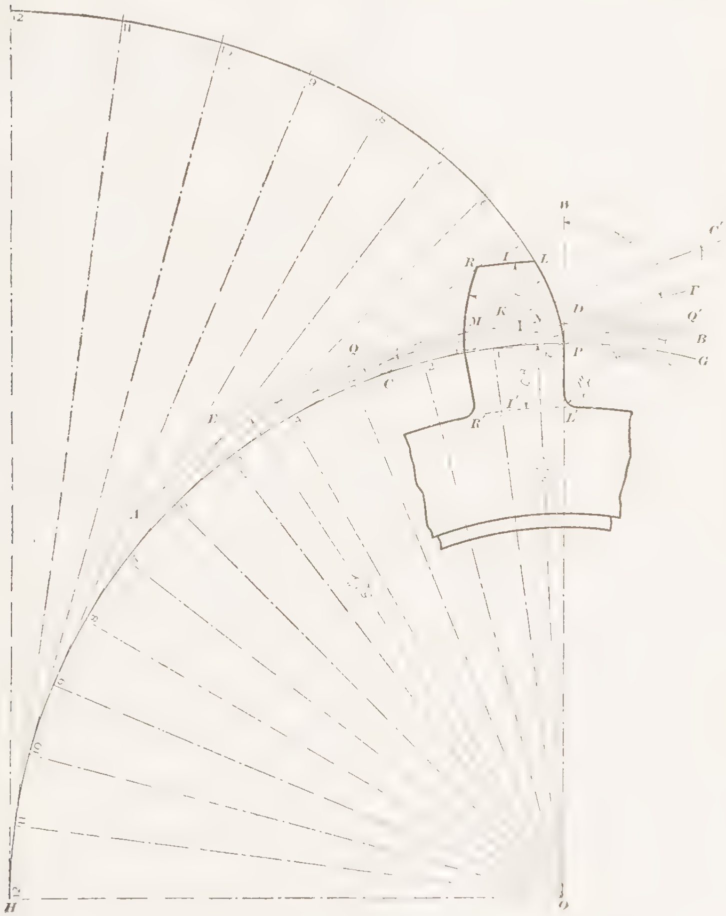

FIG. 82

length draw arcs intersecting at *C* and *C′*. Through the points of intersection of these arcs, draw a straight line connecting *C* and *C′*. The center *Q* must lie on this line. By trial find a point from which an arc can be drawn that will pass through

the involute curve $L\,P$. For involute teeth it is only necessary to find the one center Q; the centers for all the remaining teeth lie on a circle having O as a center and passing through Q. To draw the other side of the tooth, refer to Fig. **6**. Lay off on the pitch circle $M\,N = .96$ inch, same as $P\,D$ in Fig. **4**. With M as a center and $Q\,N = Q\,P$ as a radius draw an arc cutting, at Q_1, the circle passing also through Q; with Q_1 as a center and the same radius describe the part $P'\,R$ of the tooth profile above the base circle. The part $P'\,R'$ below the base circle is a part of the radius $O\,P'$.

157. In drawing any of the curves previously described, the greater the number of parts into which the describing, or base, circles are divided, the greater will be the accuracy obtained. The profile of the rack tooth used for involute gears is a straight line making an angle of 15° with a line drawn perpendicular to the pitch line. Its construction is shown in Fig. **7**, the dimensions of the tooth being the same as in Fig. **6**.

DEFINITIONS AND CALCULATIONS

158. When a revolving shaft transmits motion to another shaft parallel to it, by means of gear-wheels or tooth-wheels, whose outer rims are provided with teeth parallel to the shafts, the two gears are called **spur gear-wheels.** When the shafts are not parallel, but their axes intersect in a point, as O in Plate 1015, they are called **bevel gear-wheels.** If two bevel gear-wheels that work together have pitch diameters of the same size, they are called **miter gear-wheels.**

From what has preceded, it is evident that *the circular pitch multiplied by the number of teeth equals the circumference of the pitch circle.*

Let p = circular pitch of gear-wheel;
n = number of teeth;
d = pitch diameter;
$\pi = 3.1416$ (π is pronounced **pi**).

Then, $$d = \frac{p\,n}{\pi} \qquad (1)$$

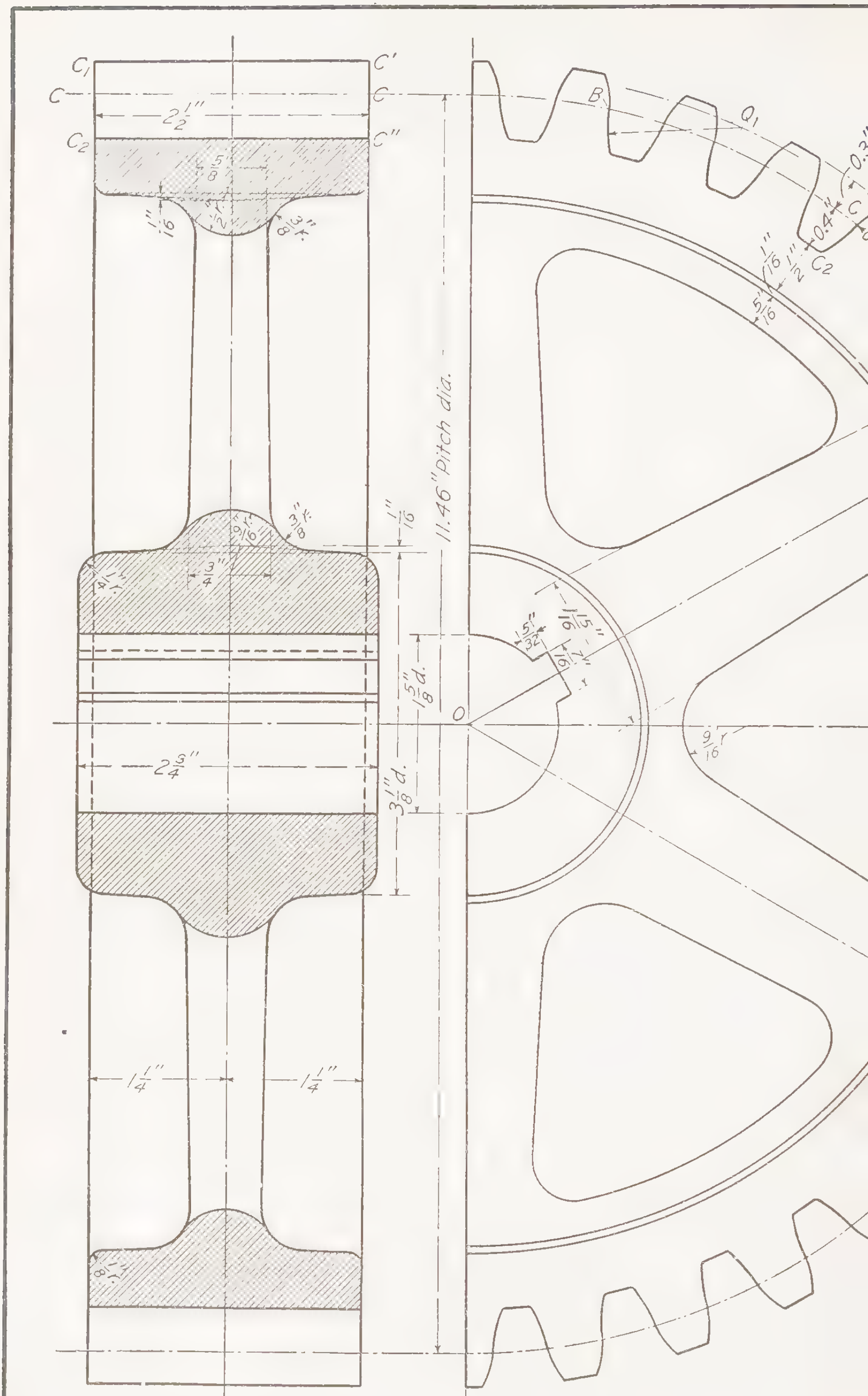

Fig. 2

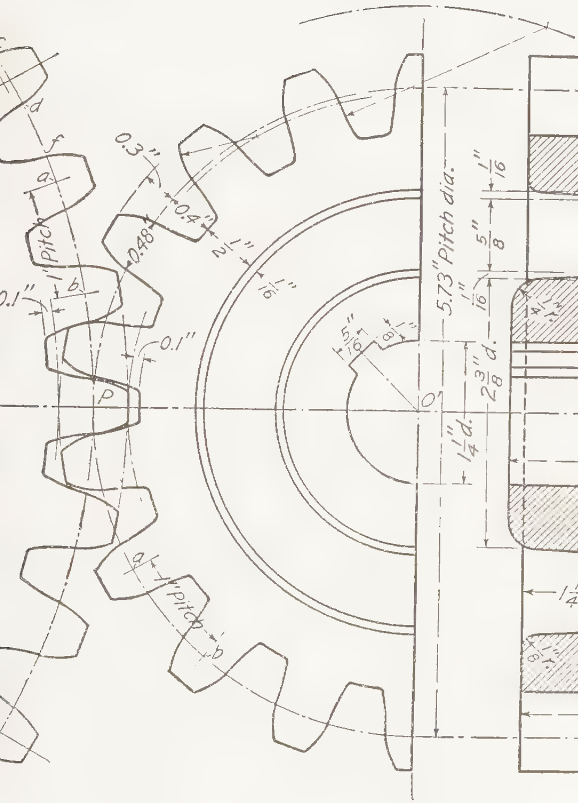

Fig. 1

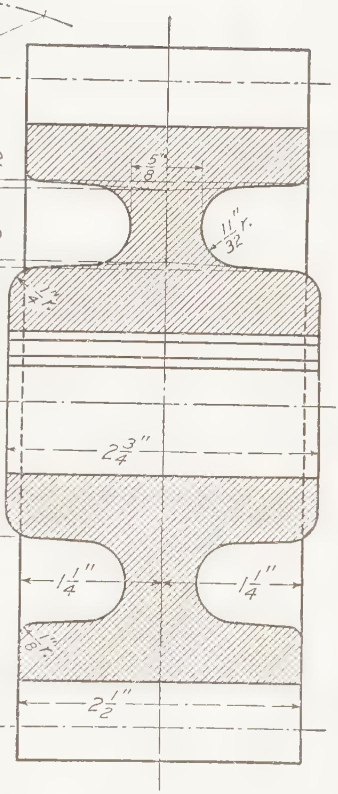

Fig. 3

GEAR AND PINION

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1014

or, *the diameter of the pitch circle equals the circular pitch multiplied by the number of teeth divided by 3.1416.*

$$p = \frac{d\,\pi}{n} \qquad (2)$$

or, *the circular pitch equals the pitch diameter multiplied by 3.1416 divided by the number of teeth.*

$$n = \frac{d\,\pi}{p} \qquad (3)$$

or, *the number of teeth equals the pitch diameter multiplied by 3.1416 divided by the circular pitch.*

When constructing cycloidal teeth for gear-wheels, the diameters of the describing circles are usually made equal to one-half the diameter of the pitch circle of a gear-wheel having 12 teeth of the same pitch as those of the gear-wheel about to be made.

Let d' be the diameter of the describing circle; then,

$$d' = \frac{12\,p}{\pi} \times \tfrac{1}{2}, \text{ or } d' = \frac{6\,p}{\pi} \qquad (4)$$

Addendum $= .3\,p$; root $= .4\,p$; thickness of teeth for cast gears is $.48\,p$, and for cut gears $\frac{1}{2}\,p$.

PLATE 1014, TITLE: GEAR AND PINION

159. Plate 1014 shows the halves of two cast gear-wheels having cycloidal teeth, which work together; also a cross-section of each gear is given. The drawing is full size, the wheels not being shown entire for want of space; to have done so it would have been necessary to make the drawing to a reduced scale. The pitch is 1 inch, the number of teeth in the large gear is 36, and in the small one 18. The pitch diameter of the large wheel is found by formula **1** to be

$$d = \frac{1 \times 36}{3.1416} = 11.46 \text{ inches, nearly}$$

The pitch diameter of the small gear

$$= \frac{1 \times 18}{3.1416} = 5.73 \text{ inches, nearly}$$

The diameter of the describing circle is found by formula 4 to be

$$d' = \frac{6 \times 1}{3.1416} = 1.91 \text{ inches}$$

For all practical purposes, the diameter of the describing circle may be taken to the nearest 16th inch. For circular pitches under $\frac{1}{2}$ inch, approximate the diameter of the describing circle to the nearest 32d inch. To find the nearest 16th or 32d, multiply the decimal part of the diameter by 16 or 32 and take the nearest whole number of the product as the number of 16ths or 32ds that the decimal represents. Thus, in the above, the decimal part of the diameter is .91 inch; $.91 \times 16 = 14.56$. The nearest whole number to 14.56 is 15; hence, the diameter of the describing circle is $1\frac{15}{16}$ inches. If the diameter had been required to the nearest 32d, $.91 \times 32 = 29.12$, and 29 is the nearest whole number; hence, the diameter would be $1\frac{29}{32}$ inches. In this case, take the diameter as $1\frac{15}{16}$ inches, approximating to the nearest 16th for all circular pitches above $\frac{1}{2}$ inch. The addendum will be $.3 \times 1'' = .3$ inch; the root will be $.4 \times 1'' = .4$ inch; and the thickness of the tooth on the pitch circle will be $.48 \times 1'' = .48$ inch.

Draw the line of centers OO' between the two axes and locate the point O $4\frac{3}{16}$ inches from the left-hand border line. With O as a center describe a semicircle having a diameter of 11.46 inches, cutting OO' in P. With O', which is $4\frac{1}{4}$ inches from the right-hand border line, as a center describe a semicircle having a diameter of 5.73 inches which shall be tangent to the first semicircle; this semicircle also cuts OO' in P. These are parts of the pitch circles. Divide the larger semicircle into $\frac{36}{2}$, or 18, equal parts by using the protractor. This is accomplished by laying the protractor on the drawing in such a manner that the center of the protractor coincides with the center O of the gear-wheel and then laying off on the pitch circle 18 divisions, each equal to 10°. The reason for this will be clear when it is remembered that there are 360° in a circle, or $\frac{360°}{2} = 180°$ in a semicircle, and as there are 18 teeth in the semicircle, $180° \div 18$

$=10°$, which is the angle between two lines drawn from the centers of any two consecutive teeth to the center O. In a like manner, any circle may be divided into parts by using the protractor.

Make $C\,C_1=.3$ inch = addendum, and $C\,C_2=.4$ inch = root. With O as a center and $O\,C_1$ and $O\,C_2$ as radii, describe semicircles, which are parts of what are called addendum and root circles, to represent the tops and bottoms of the teeth. Consider the points of division just laid off on the pitch circle as the centers of the teeth, and lay off on each side one-half of the thickness $c\,d$ of the tooth, or $.48\times\frac{1}{2}=.24$ inch. Upon another sheet of paper strike a short arc of the pitch circle of the large gear and construct the profile of the tooth as described in connection with Fig. 4, Plate 1013, using describing circles $1\frac{5}{16}$ inches in diameter. (Send in this pencil work with the plate for correction.) Having found the centers Q and Q_1 of the circular arcs used for the profiles of the teeth, draw circular arcs through these centers, as previously described; then, with O (see Plate 1014) as a center and the same radii describe semicircles; these semicircles will contain the centers of the circular arcs which form the teeth profiles. With the point A as a center and a radius equal to the radius of the face of the tooth (found on the other sheet of paper), describe an arc intersecting the circle of face centers at Q. With Q as a center and the same radius, describe the arc $A\,D$ for the face of the tooth, the point D being the point of intersection of $A\,D$ with the addendum circle. In the same way draw the remaining faces of the teeth. To draw the flanks take a point representing the intersection of a tooth profile with the pitch circle (the point B, for example) as a center and a radius equal to the radius of the flank found on the other paper on which the tooth profile was drawn, and describe an arc intersecting the circle of the flank centers in Q_1. With Q_1 as a center and the same radius, describe the flank curve, stopping at the root circle. Draw the flanks of the remaining teeth in the same way and then put in the fillets. The teeth of the pinion should be constructed in the same manner except that a short arc of the pitch circle of the pinion is used in the pencil construction.

Fig. 2 is a conventional method of drawing cross-sections of gears. Draw the vertical center line of this figure 2 inches from the left-hand border line and that of Fig. 3 2 inches from the right-hand border line. The hubs and rims are sectioned, but the teeth and arms are not. This is similar to the wheel shown on Plate 1005. This method of sectioning makes the views clearer and saves the time spent in sectioning. It will be seen from this cross-section, that the inside of the rim is not straight but decreases in diameter toward the vertical center line of the gear. If the lines representing the inner side of the rim at both sides of the arms are produced, they will intersect the center line at one point, which is $\frac{1}{16}$ inch below the point of intersection of a straight rim. The thickness of the rim at this point is indicated in the elevation, Fig. 1, by a circle $\frac{1}{16}$ inch nearer the center of the gear than the circle which represents the inside of the rim. The same remarks apply to the elevation and section of the pinion.

In Fig. 3 the entire gear is sectioned, except the teeth. There should now be little difficulty in finishing the plate without further instructions.

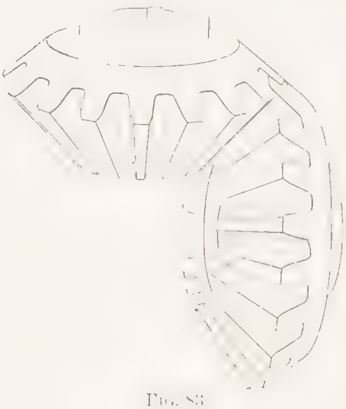

Fig. 83

PLATE 1015, TITLE: BEVEL GEARS

160. On Plate 1015 are to be drawn in section and projection two cast bevel gears whose axes intersect at right angles. The number of teeth in the large gear is 20, in the pinion 16. The circular pitch is 1 inch; the teeth are to be of the cycloidal form, having a face 2 inches wide. The perspective view of these gears given in Fig. 83 will give a clearer understanding of their appearance. In any kind of gearing, whether spur, bevel, or spiral, the smaller wheel is called the **pinion.**

Calculate the pitch diameters, addenda, roots, and describing circles by the same rules that were given for spur gears.

Large Wheel
Pitch Dia. 6.37"
Pitch 1"
20 Teeth

Pinion
Pitch Dia. 5.09"
Pitch 1"
16 Teeth

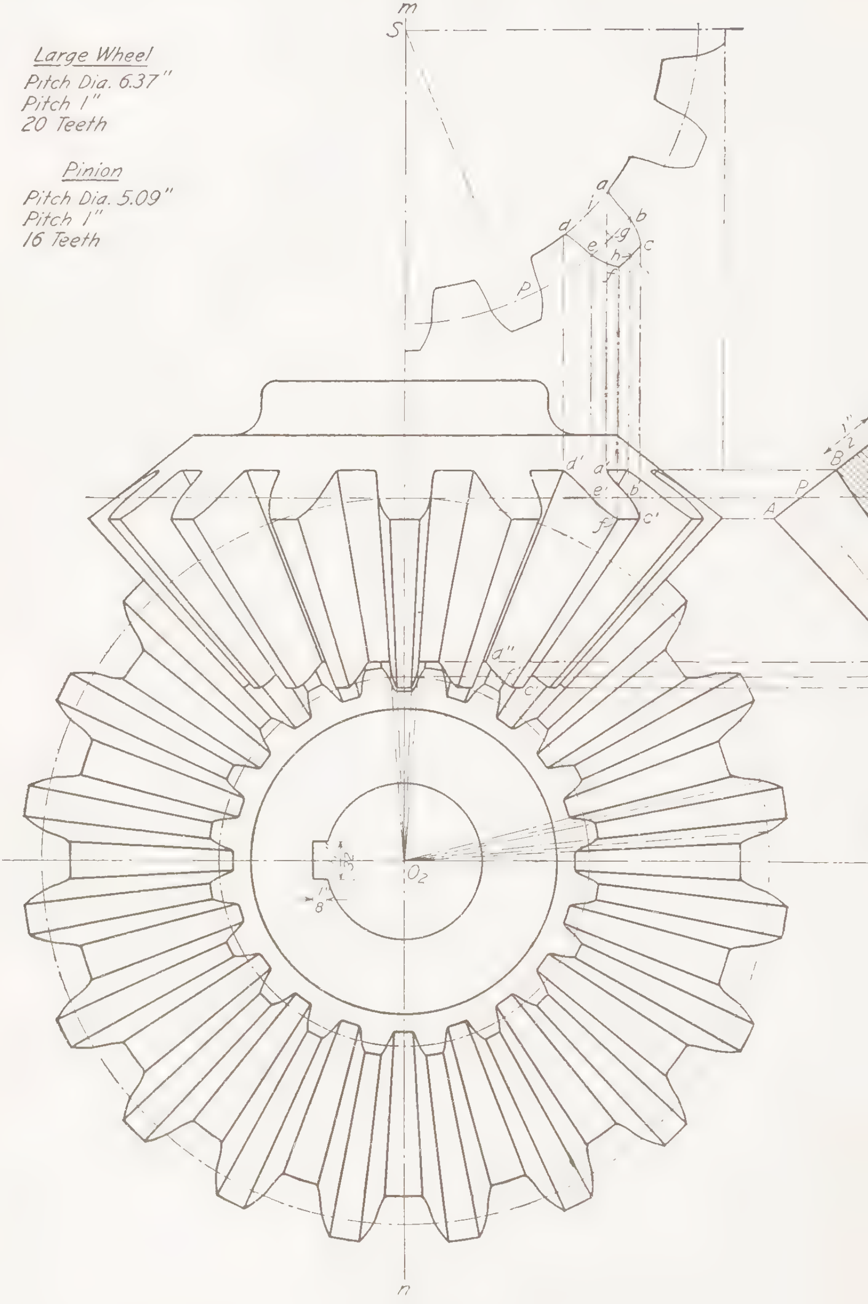

Fig. 2

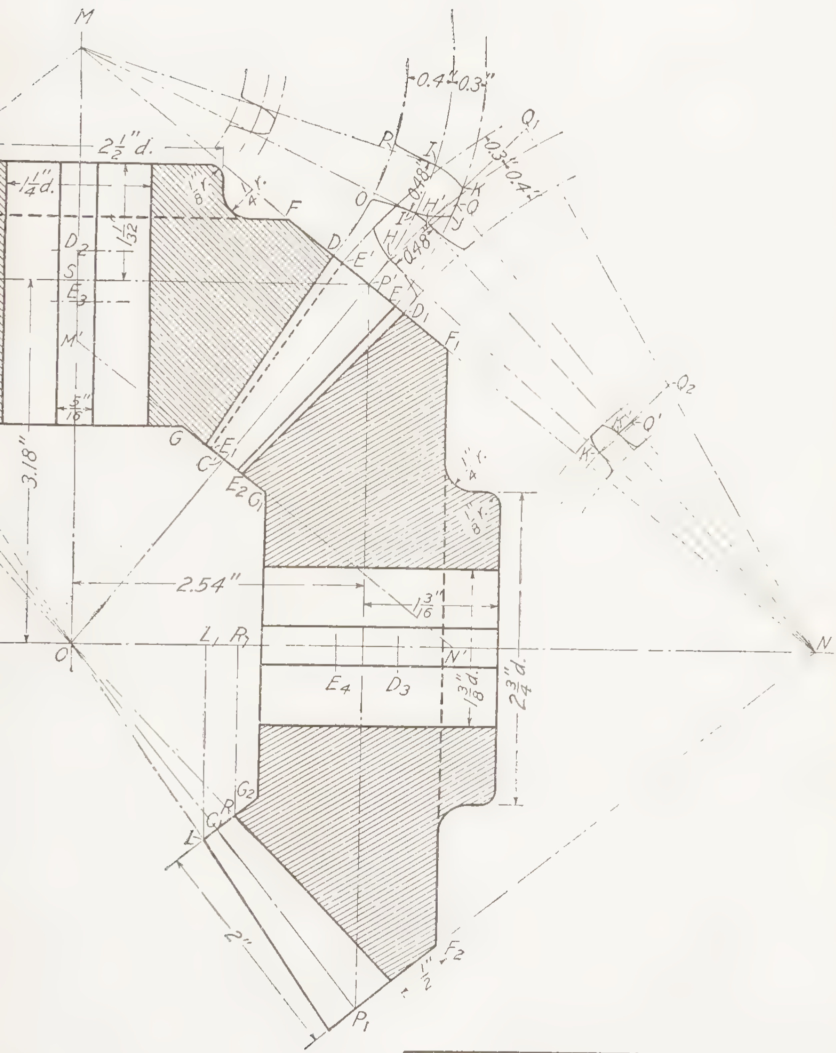

Fig. 1

BEVEL GEARS

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$$\text{Diameter of pinion} = \frac{16 \times 1''}{3.1416} = 5.09 \text{ inches}$$

$$\text{Diameter of the large gear} = \frac{20 \times 1''}{3.1416} = 6.37 \text{ inches}$$

$$\text{Diameter of describing circle} = \frac{6 \times 1''}{3.1416} = 1.91 \text{ inches}$$

Take 1.91 as $1\frac{15}{16}$ inches, as in the last plate.

Addendum = .3 inch; root = .4 inch. The sectional view, Fig. 1, must be drawn first. Draw PP' and through some point P' on this line draw $P'P_1$ perpendicular to it. Locate the point P' $4\frac{7}{16}$ inches from the right-hand border line and $4\frac{3}{4}$ inches below the top border line. Lay off PP' equal to the diameter of the pinion = 5.09 inches; also $P'P_1$ equal to the diameter of large gear = 6.37 inches. Bisect PP' and $P'P_1$, and draw OM and ON perpendicular to those lines at the point of bisection; they intersect in O. OM and ON are the axes of the two gears and intersect at right angles as required. Draw POP_1 and $P'O$. Through P draw APM perpendicular to OP. Through P' draw $MP'N$ perpendicular to OP', and through P_1 draw P_1N perpendicular to OP_1. PM and $P'M$ intersect at M on the line OM; $P'N$ and P_1N intersect at N, on the line ON. Lay off $P'C'$, PC, and P_1C_1, each equal to 2 inches, or the width of the face of the teeth; these lines are called the **pitch lines**, and the width of the face of the teeth is always measured on these lines. Lay off PA equal to .3 inch = the addendum, and PB equal to .4 inch = the root. Lay off $P'E$ and $P'D$ for the addendum and root of the other side, and $P'E'$ and $P'D_1$ for the addendum and root of the large gear. All these addenda and roots are each equal to .3 inch and .4 inch, respectively. In bevel gears, all straight lines of the tooth profiles pass through the point of intersection O of the axes; hence, draw AO, and AA' will be the projection of the top of the tooth. Draw BO, and BB' will represent the bottom of the tooth, the line $A'CB'$ being perpendicular to OP. Make BF', DF, D_1F_1, etc. each equal to $\frac{1}{2}$ inch, according to dimensions. Join F', F, F_1, and F_2 with O, intersecting the perpendiculars through C, C', and C_1 (namely, the lines $A'CB'$, etc.

produced) at G', G, G_1, and G_2. $G'G$ and G_1G_2 will represent the bottom of the gears. The rest of the sectional part can be drawn from the dimensions.

161. To show the shape of the teeth, proceed as follows: For the large gear, take N as a center, NP' as a radius, and describe an arc. Choose a point H and lay off $HH' = .48$ times the pitch $= .48$ inch, or the width of the tooth. With NE' and ND_1 as radii, describe the addendum and root circles. Roll the describing circles upon the arc whose radius is NP' and construct the tooth profile in exactly the same manner as in Fig. 4 of Plate 1013, QH and Q_1H' being the radii of the faces and flanks. To show the shape of the same tooth at C', draw $C'N'$ perpendicular to OP', or, what is the same thing, parallel to NP'. With $N'C'$ as a radius and N as a center, describe an arc. Draw NH and NH', and the distance between the points of intersection on the arc just drawn, measured on that arc, will be the pitch of the gear at the bottom of the tooth. With the same center and $N'E_1$ and $N'E_2$ as radii, describe arcs representing the addendum and root circles. Draw NQ and NQ_1, also QH and Q_1H'. Through K draw KQ' parallel to HQ, and through K' draw $K'Q_2$ parallel to $H'Q_1$; the points of intersection Q' and Q_2 of these lines with NQ and NQ_1 are the centers for the face and flank of the tooth at K and K'. Circles passing through these points concentric with N contain the centers of all the circular arcs forming the tooth profiles that may be laid off upon the arc whose radius is NK. The whole process is called *developing the teeth of bevel gears*.

In the same manner construct the tooth curves for the pinion, using the same describing circles, $1\frac{15}{16}$ inches in diameter, and MP', $M'C'$ as radii, instead of NP' and $N'C'$.

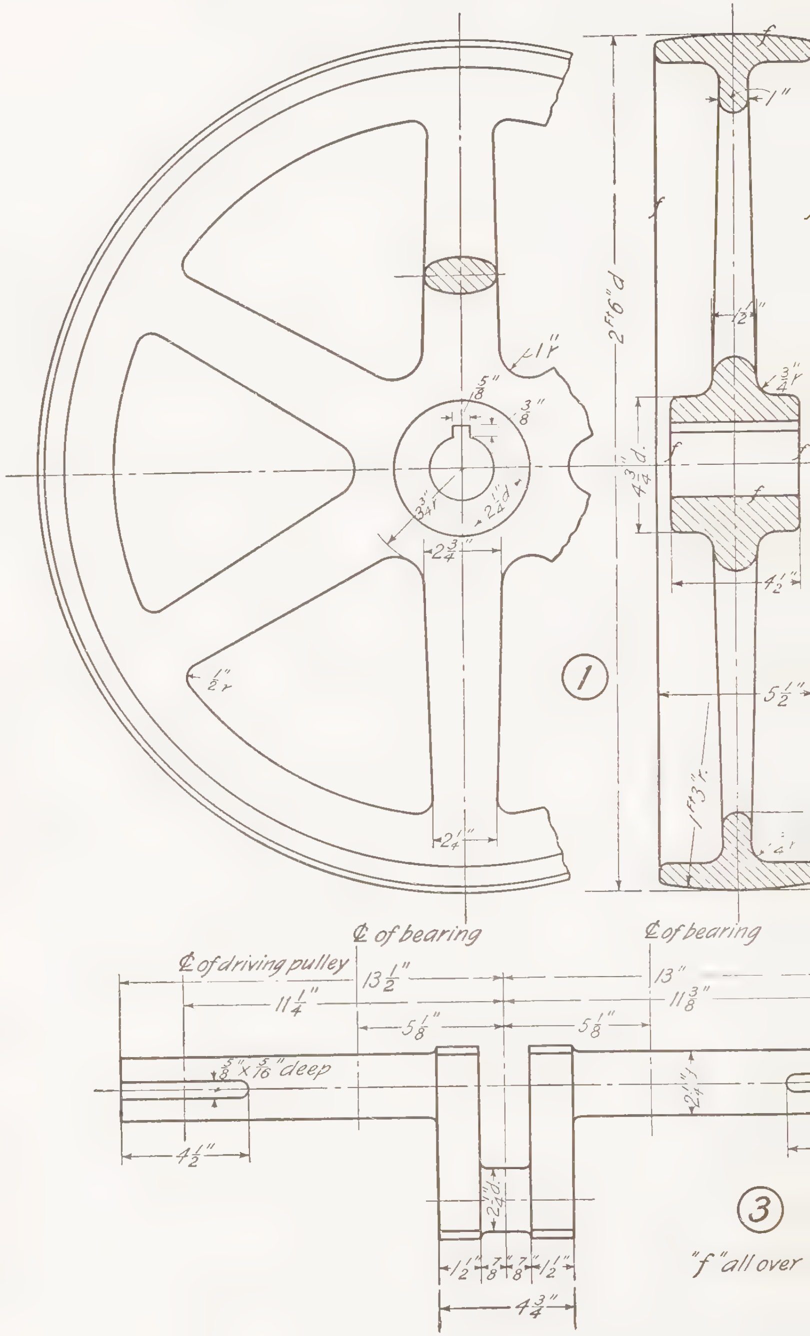
162. To construct the other view, draw first the projection of the pinion. Draw the center line mn 4 inches from the left-hand border line. Produce the lines FF', DB, $P'P$, and EA across the drawing, as shown. Choose a point S on mn as a center and draw a quadrant with a radius, as SP, equal to the radius of the pinion. Project the points D and E upon MO in D_2 and E_3. With S as a center and the distances

E_3E and D_2D as radii, describe quadrants to represent the tops and bottoms of the teeth, that is, the projection of the addendum and root circles of the pinion in Fig. 2. Since the whole pinion contains 16 teeth, the quadrant will contain 4 teeth; hence, divide the quadrant into 4 equal parts on the pitch circle to represent the centers of the teeth. Lay off on each side of the points of division distances $g\,e$ and $g\,b$, each equal to one-half the thickness of the tooth (as measured at $I\,I'$, Fig. 1). On each side of the points of division on the addendum circle lay off $h\,f$ and $h\,c$, each equal to one-half the thickness of the top of the tooth on the addendum circle (as measured at $J\,K$, Fig. 1). On each side of the points of division on the root circle lay off $i\,d$ and $i\,a$, each equal to one-half the thickness of the tooth at the root, as $O\,P$, Fig. 1, measured on the root circle. Having now three points on each side of all the teeth to the right of the center line $m\,n$, project them upon the lines $E\,A$, $P'\,P$, and $D\,B$, produced as shown. For example, project f and c upon $E\,A$ in f' and c'; e and b upon $P'\,P$ in e' and b'; d and a upon $D\,B$ in d' and a'. Draw a curve through these points, either by using an irregular curve or by circular arcs. This remark also applies to the other curves shown in the quadrant.

163. The tooth curves in Fig. 1 must be drawn as accurately as possible, but those shown in Fig. 2, being oblique projections, are drawn to satisfy the eye, and no particular accuracy is required. To find the points on the tooth curves at the bottom of the pinion, describe a circle, having a center O_2 upon $m\,n$, which shall be tangent to $P\,P'$ and have a diameter equal to 6.37 inches = the diameter of the large gear. Through B' and A', Fig. 1, draw lines parallel to $O\,O_2$; also draw other lines through O_2 and the points d', f', c', etc., cutting the lines first drawn in d'', f'', c'', etc. Two points are considered enough in this case, as the curves are very short. They may be drawn in with the irregular curve in the same manner as the tops. The other teeth are drawn in a similar manner. Draw the middle tooth first. The left-hand half of the pinion is exactly the same as the right-hand half.

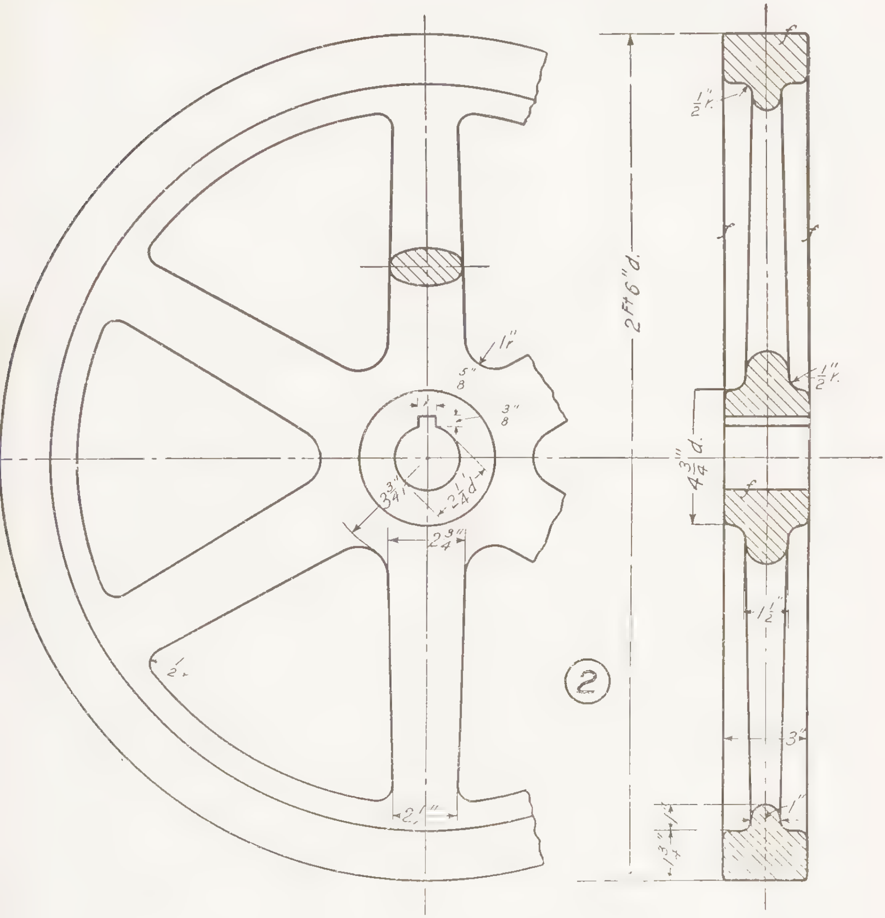
164. To draw the projection of the large gear, project the points E', D_1, L, and R upon the axis $O\,N$, in the points E_4, D_3, L_1, and R_1, and with O_2 as a center and radii equal to $E_4 E'$, $D_3 D_1$, $L_1 L$, and $R_1 R$, describe circles to represent the addendum and root circles of the tops and bottoms of the teeth in Fig. **2**. Divide the pitch circle into 20 equal parts, to correspond with the number of teeth in the large gear, beginning with a point $\frac{1}{2}$ inch from the point of intersection of the pitch circle with the center line $m\,n$. Lay off on each side of these pitch-circle divisions, distances equal to one-half the thickness of the teeth = one-half of $H\,H'$ in Fig. **1**. By exactly the same method that was used to lay off the thickness of the teeth at the top and bottom on the quadrant, lay off the thickness of the top and bottom of the teeth on the addendum and root circles in Fig. **2**. Draw the bottoms of the teeth in exactly the same manner as the bottoms of the pinion teeth were drawn. All the teeth of the large gear are alike in the projected view.

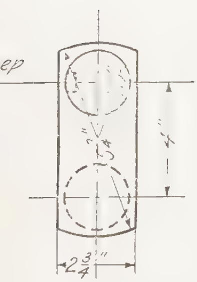
165. Bevel gears are always measured according to their largest pitch diameter, as $P\,P'$ and $P'\,P_1$. If a bevel gear were spoken of as 12 inches in diameter, it would be understood that the largest pitch diameter was 12 inches.



2Ft6"d
1"
1/2"
1"r
3/4"r
5/8"
3/8"
4 3/4"d.
3 3/4"r
2 1/4"d
2 3/4"
4 1/2"
5 1/2"
1/2"r
1Ft3"r.
2 1/4"
℄ of bearing
℄ of bearing
℄ of driving pulley
13 1/2"
13"
11 1/4"
11 3/8"
5 1/8"
5 1/8"
5/8" x 5/16" deep
2 1/4"
4 1/2"
2 1/4"d.
1/2"
7/8"
7/8"
1/2"
4 3/4"
"f" all over

1
3





1	Key for 2&3-3 long $\frac{3}{8}\times\frac{13}{16}$	5	Steel		
1	Key for 1&3-$4\frac{1}{8}$" long $\frac{3}{8}$"x$\frac{11}{16}$"	4	Steel		
1	Crank Shaft	3	Forged steel		
1	Fly wheel	2	Cast iron	Pattern	B
1	Driving pulley	1	Cast iron	Pattern	A

DRIVING PULLEY FLY WHEEL AND CRANK-SHAFT

DRAWN BY.................

DATE.................

1016

NAME, CLASS LETTERS, AND NUMBER

MECHANICAL DRAWING
(PART 3)

DRAWING PLATES—(Continued)

PLATE 1016, TITLE: DRIVING PULLEY, FLYWHEEL, AND CRANK-SHAFT

1. Plates 1016, 1017, 1018, 1019, and 1020, which are to be drawn in the order mentioned, are the details of a steam engine, the assembly drawing of which is to be shown in Plate 1021. Together, these plates form the complete drawings of a steam engine, and the design is one that will give a great deal of practice in laying out various mechanical details.

2. Of the parts shown on Plate 1016, the pulley and flywheel should easily be constructed without any additional explanation, by simply following the instructions given in connection with Plate 1005. Locate their horizontal center lines $4\frac{9}{16}$ inches below the upper border line and the vertical center lines of the two views of part **1**, $4\frac{5}{8}$ inches and 7 inches, respectively, from the left-hand border line. The vertical center lines of part **2** should be $4\frac{3}{8}$ inches and $1\frac{3}{8}$ inches, respectively, from the right-hand border line.

Part **3** is a forged-steel crank-shaft, on one end of which is to be mounted the driving pulley and on the other end the flywheel, both held in position by keys partly sunk into the shaft and partly into the hubs. The crank-shaft consists of the shaft proper and of two arms projecting at right angles, called the *webs,* which are connected by a short stud-like part,

the *crankpin.* The vertical center line of the flywheel is $11\frac{3}{8}$ inches (see Plate 1016) from that of the crankpin, the latter center being coincident with that of the cylinder and connecting-rod, while the center line of the driving pulley is $11\frac{1}{4}$ inches to the other side of the crankpin center. It should be noticed that on the plate the abbreviation ℄ has been used for the term center line.

After the flywheel and driving pulley have been mounted on the shaft, the latter is placed in the bearings of the engine frame. The centers of these bearings are indicated as being $5\frac{1}{8}$ inches to either side of the crankpin center. It will be noticed that the two keyways are not alike, the one for the driving pulley being cut clear to the end, while the one for the flywheel stops a short distance from the end. The stroke of the engine is determined by the distance between the horizontal center line of the crankpin and that of the shaft. This distance is here 4 inches and the stroke will therefore be $4 \times 2 = 8$ inches.

The shaft is $2\frac{1}{4}$ inches in diameter; the web is $2\frac{3}{4}$ inches wide by $1\frac{1}{2}$ inches thick and rounded off to a radius of $6\frac{3}{4}$ inches. Locate the center line of shaft 3 inches above the lower border line, and the vertical center line through the crank and end view of shaft $4\frac{15}{16}$ inches and $9\frac{3}{4}$ inches, respectively, from the left-hand border line.

PLATE 1017, TITLE: ENGINE FRAME

3. On Plate 1017 are shown plan, elevation, end view, and cross-section of the engine frame, also details of bearings and caps, all drawn to a scale of $3'' = 1$ ft. The elevation and plan are to be drawn together. Locate the center lines of these two views $2\frac{3}{4}$ inches and $6\frac{3}{4}$ inches, respectively, below the upper border line and extend the lower one the whole length of the plate, as it is also to serve for the end view. The vertical center line, which in both views passes through the center of crankshaft, should be $2\frac{5}{16}$ inches from the right-hand border line. Locate the main horizontal dimensions from this center line. Draw the base line of the elevation 9 inches (to scale) below

the center of the crank-shaft and make the base of the pedestal at crank-shaft end of frame $11\frac{1}{2}$ inches long and $15\frac{1}{2}$ inches wide. The position of the center line of the base at the cylinder end is found by laying off 3 feet $3\frac{1}{8}$ inches (the distance between shaft center and cylinder end of frame) and then measuring back 8 inches; the base at this end is 14 inches long by $9\frac{1}{2}$ inches wide.

The cross-section taken at *A A* indicates the shape of the frame, showing that the latter, on the whole, is cylindrical. The elevation shows that the lower part of the frame curves downwards before joining the base under the crank-shaft. The form of the curves of the upper and the lower parts of the frame as they appear in the elevation are determined by locating the number of points from the vertical and horizontal center lines and base line, as shown by the dimensions on the drawing. The points are then joined by lines drawn with the irregular curve. Before joining the upper curve to the cylindrical part of the frame, draw first the bead-like rib seen at this end, indicated by a circle $\frac{3}{4}$ inch in diameter (see section *A A*) and draw the curve tangential to this circle. The pedestal is pyramidal in shape, as seen in the elevation, with a semicircular opening in the top. To show this opening properly in the plan view, the special construction shown in Fig. 1 is required, in which the lower view represents the end of the frame in elevation. The semicircle, $6\frac{3}{4}$ inches in diameter, representing the lower part of the opening, is supposed to have been turned at right

FIG. 1

angles about its vertical radius so as to lie in the plane of the paper. Only a quarter circle has been shown—the other part being symmetrical to it—and this has been divided into four equal parts, as shown at *a b, b c, c d,* and *d e*. From these division points, projectors are drawn at right angles to side of frame, as indicated by lines $a\,a_1$, $b\,b_1$, $c\,c_1$, and $d\,d_1$.

A plan view of the opening is now to be drawn above the elevation by first drawing the semicircle $a_2\,e_2\,a_2$, representing a plan of the opening, and dividing it in eight parts, since the whole semicircle is shown here. Draw horizontals from the points a_2, b_2, c_2, etc., letting them intersect verticals from the points a_1, b_1, c_1, etc., the points of intersection being points on the curve, as shown at a_3, b_3, c_3, etc. Draw horizontals through the two points a_3 toward the center line. Then $k\,a_3\,c_3\,a_3\,l$ will indicate the outline of the opening as it would appear in the plan view if the bearings did not project beyond the sides of the opening. Verticals have been shown as intersecting the horizontals from only the lower half of the semicircle, but it is understood that they should be continued so as also to intersect those in the upper half, this part of the view being symmetrical on the lower half.

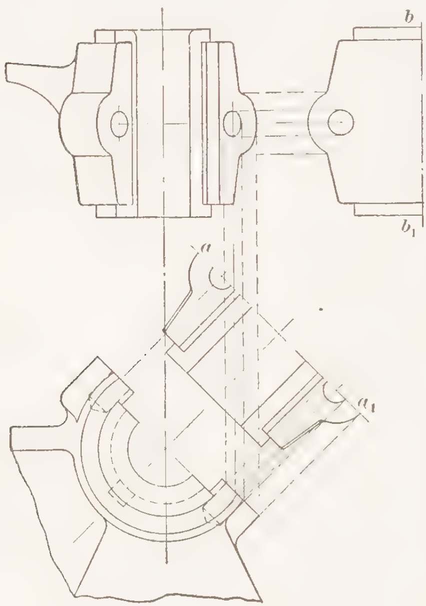


Fig. 2

4. The face of the crank-shaft bearing is inclined at an angle of 45° with the horizontal, and has two $\frac{3}{4}$-inch studs tapped into the frame for each cap. The two halves of the

bearing are partly lined with Babbitt [illegible] inch thick, the bearing itself being made of bronze. For aid in drawing these bearings in the plan view, reference should be made to Fig. 2. The method employed is identical with that used in Fig. 1, and for this reason no detailed description is given. The dimensions $a\ a_1$ of the plan view in the main elevation in Fig. 2 are derived from the plan view of the cap, part **4**, the outlines being identical for both parts. The outlines of the stud holes and the curved parts of the frame adjoining them are divided into a convenient number of parts, and these points are projected to the main elevation. Another plan view $b\ b_1$, located as shown in Fig. 2, is subdivided in a similar manner, and from the points of division horizontal projection lines are drawn intersecting vertical lines drawn from the elevation at the points indicated. When these points are joined by circular arcs, the centers of which must be found by trial, the true outlines of frame and holes as they will appear in the plan will be found.

5. The walls of the frame are $\frac{5}{8}$ inch thick and have raised surfaces that are bored for the crosshead slide, as indicated in the end views and by means of dotted lines in the plan view and the elevation. These surfaces are 12 inches long and bored to a diameter of $6\frac{1}{4}$ inches, the centers of the surfaces being $15\frac{1}{8}$ inches from the end of the frame. There is at the center of the upper surface a grease or oil receptacle through which the crosshead is oiled. Near the end of the opening in the side of the frame will be seen the two bosses that support the valve-stem guide by means of two $\frac{3}{4}$-inch studs $4\frac{7}{8}$ inches long with hexagon nuts, part **6**.

The frame at the cylinder end is bored out to receive the projecting boss on the end of the cylinder casting. The cylinder is held in position by the five studs, part **7**, that are tapped into the frame end. In the end view, shown to the left of elevation, the plan of drilling and tapping for these studs is indicated, from which it is seen that the studs are not equally spaced. Locate the center line of this view $2\frac{1}{4}$ inches from the left-hand border line.

Next draw the cross-section taken on the line *A A* of the elevation, with its center line $2\frac{7}{16}$ inches from the left-hand border line. This section is intended to represent the right-hand part of the elevation, but the parts beyond the plane of section have been omitted to avoid confusion of lines. The outlines of this section are circular arcs, the exterior one having a radius of 4 inches. Locate its center $2\frac{1}{2}$ inches below the top border line. To define the height of the frame in this section, draw a horizontal line at a distance above its lowest point equal to the height of the frame along the line *A A* (this distance should be measured on the drawing) in the elevation. *A A* should cut all four curves at as nearly right angles as is possible. The frame is $\frac{5}{8}$ inch thick at this place and a circular arc with a radius of $3\frac{3}{8}$ inches is therefore drawn concentric to the former arc. Tangential to this inner arc and to the horizontal top boundary line, draw two circles with a radius of $\frac{3}{8}$ inch; draw fillets between these circles and the outside arc.

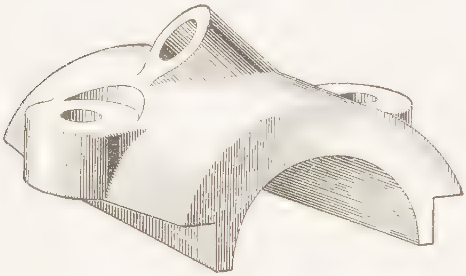
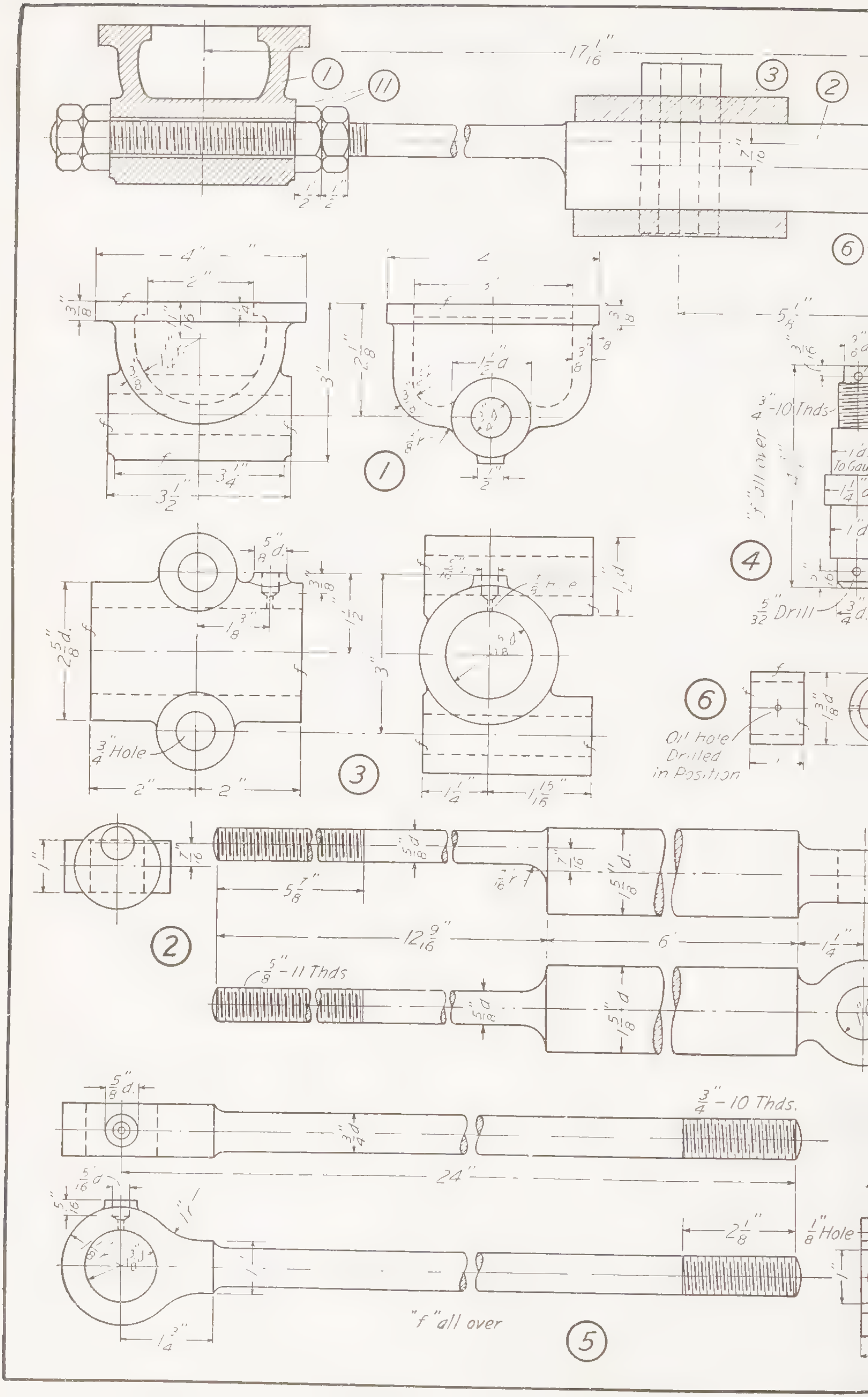
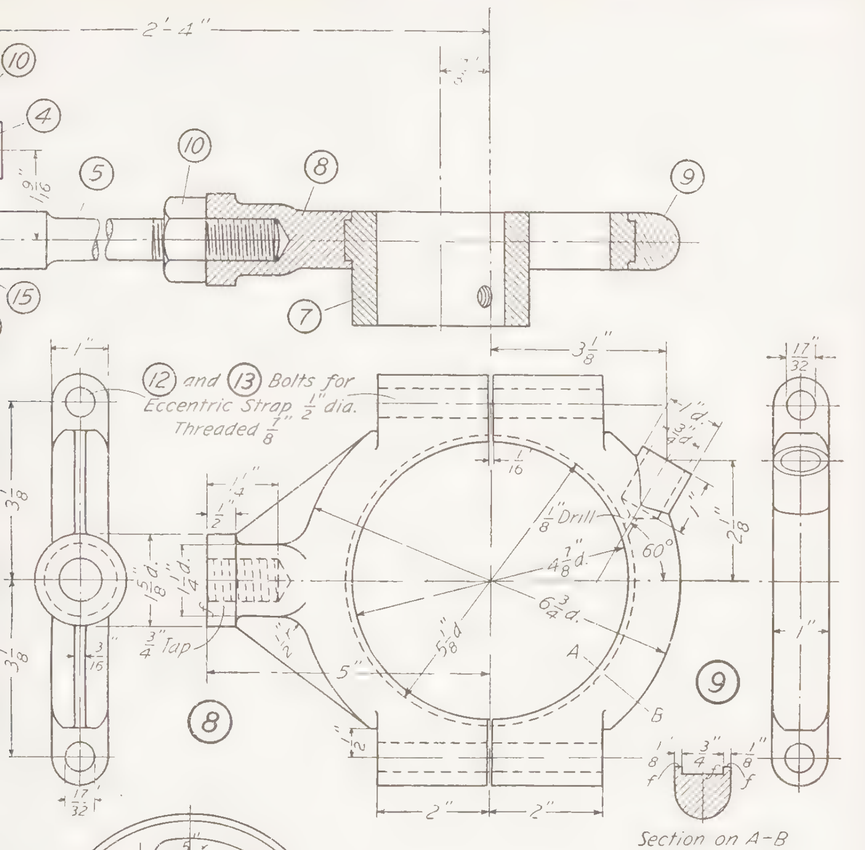


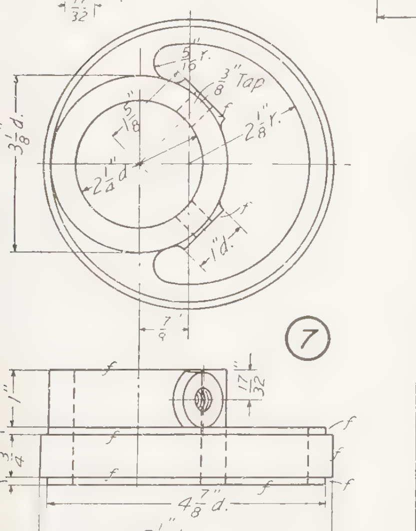
FIG. 3

6. Parts **2** and **3** are the bearing brasses made in halves and partly lined with antifriction or Babbitt metal. They are bored to a diameter of $2\frac{1}{4}$ inches and are $5\frac{1}{2}$ inches long. To fit crank-shaft bearings they are turned to a diameter of $3\frac{1}{4}$ inches and are prevented from turning around by $\frac{5}{8}$-inch-diameter brasses on each half, which fit into recesses in the frame and in the cap, as seen in the elevation of the frame. They are drawn on horizontal center lines that are located at distances of $1\frac{1}{2}$ inches and $1\frac{3}{4}$ inches, respectively, above the lower border line. The vertical center lines for the end views should be drawn $2\frac{1}{16}$ inches from the left-hand border line.



Oil hole
Drilled
in Position
3/4" Hole
5/8" - 11 Thds
3/4" - 10 Thds.
3/4" - 10 Thds
"f" all over over
5/32" Drill
1/8" Hole
"f" all over





2	$\frac{5}{32}$" Cotter Pins.	16	Steel		
1	Finished Washer.	15	Steel		
2	$\frac{3}{8}$"-16 Thd. Set Screws $\frac{3}{4}$" Long	14	Steel		
2	$\frac{1}{2}$"-13 Thd. Nut and Lock Nut	13	Steel		
2	$\frac{1}{2}$"-13 Thd. Hex. Bolts $4\frac{7}{8}$" Long	12	Steel		
4	$\frac{5}{8}$"-11 Thd. Hex. Nuts $\frac{1}{2}$" Thick	11	Steel		
2	$\frac{3}{4}$"-10 Thd. Hex. Nut for 4 X 5	10	Steel		
1	Half Eccentric Strap, Rear.	9	Cast Iron	Pattern	E
1	Half Eccentric Strap, Front.	8	Cast Iron	Pattern	D
1	Eccentric Sheave	7	Cast Iron	Pattern	C
1	Bush for 5	6	Brass		
1	Eccentric Rod.	5	Forged Steel		
1	Pin for 2 X 5	4	Steel		
1	Valve Rod Guide	3	Brass	Pattern	B
1	Valve Rod	2	Steel		
1	Valve	1	Cast Iron	Pattern	A

VALVE GEAR

DRAWN BY ________

DATE ________

1018

Next draw the cast-iron bearing cap, part **4**, with its vertical center line $7\frac{1}{8}$ inches from the right-hand border line. A perspective view of such a cap is shown in Fig. 3. The horizontal center lines for the plan and elevation are $\frac{3}{4}$ inch and $2\frac{3}{4}$ inches, respectively, above the lower border line. The cap is bored out to a radius of $1\frac{3}{8}$ inches to fit the top brass, and the grease cup is made with top at an angle of 45° with the horizontal center line in order that, when placed in position on the frame, the upper edge of the cap will have a horizontal position.

PLATE 1018, TITLE: VALVE GEAR

7. The cross-section assembly in the upper part of Plate 1018 shows the relation and connection between valve, valve rod, guide, eccentric rod, eccentric strap, and eccentric sheave, all these parts being detailed elsewhere on the drawing. All the parts are drawn half size, and all are provided with reference numbers corresponding with those on the assembly. Draw the details first, then the cross-section assembly.

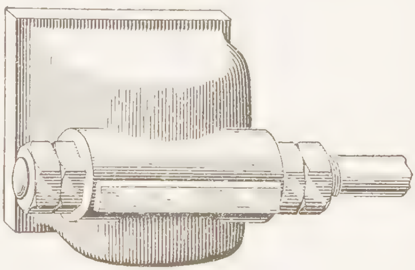


Fig. 4

8. Part **1**, the valve, shown in perspective in Fig. 4, is made of cast iron from pattern *1018–A*. It is a cup-shaped device, through the top of which the valve rod, part **2**, passes. Its position in the steam chest regulates the entrance of the steam through the ports that connect with the ends of the cylinder and permits also the exhaust steam to pass from these ports into the exhaust port, which connects with the exhaust pipe.

Locate the horizontal center line of the valve-rod boss $3\frac{7}{8}$ inches below the upper border line, and the vertical center lines of the two views $1\frac{3}{4}$ inches and $4\frac{1}{2}$ inches, respectively,

from the left-hand border line. The left-hand view is a plan and the other an end view. On the outer side of the boss is seen a rib-like projection; this slides on a corresponding rib on the steam-chest cover, and serves to hold the valve in place.

9. The valve rod, part **2**, is supported by the valve-rod guide, part **3**, which, in turn, is bolted to the engine frame at the left-hand end of the opening shown in the elevation of the frame, Plate 1017. The two cylindrical parts of the valve rod, part **2**, have not a common axis, but their axes are eccentric to an extent of $\frac{7}{16}$ inch. The purpose of making the rod in this manner is to give a large sliding surface to the *slide*, the part in contact with the guide, and at the same time to bring

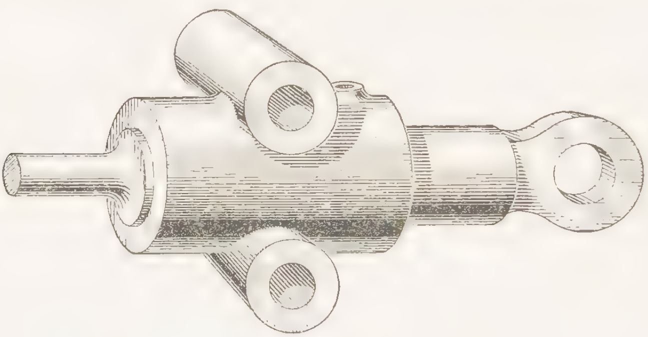


FIG. 5

the valve rod proper nearer the cylinder than would be the case if its axis were a continuation of that of the slide.

Draw the horizontal center line of the elevation and end view of part **3**, $6\frac{1}{16}$ inches from the upper border line, and let the vertical center lines be a continuation of those for the valve. At one end of the elevation is located a boss provided with a hole for lubricating purposes. It is also visible in Fig. 5, which is a perspective view of the guide and the end of the valve rod, part **2**. Place the horizontal center lines of the slide in the two views $4\frac{7}{8}$ inches and $3\frac{9}{16}$ inches, respectively, above the bottom border line. Draw the vertical center line of the eye $8\frac{1}{16}$ inches from the left-hand border line, and that of the end view 1 inch from the same border line. The

pin, part **4**, is entirely cylindrical and requires therefore only one view. Its vertical center line is 8 inches from the left-hand border line and its top $3\frac{5}{16}$ inches below the upper border line.

10. The eccentric rod, part **5**, has at one end an eye into which is fitted a bushing, part **6**. One side of this end of the rod rests against a shoulder on the pin, part **4**. At the other side there is a washer, part **15**, held in place by the split pin, part **16**. The other end of the rod screws into one of the eccentric strap halves, part **8**. Draw the horizontal center lines of the views $2\frac{3}{8}$ inches and $1\frac{1}{16}$ inches, respectively, above the bottom border line. The vertical center lines of the end view and of the eye in the other views should be drawn $1\frac{1}{8}$ inches and $8\frac{5}{16}$ inches, respectively, from the left-hand border line. The clamping nuts, part **10**, used on the eccentric rod and on the pin, part **4**, are of standard size and do not require separate detail drawings. The bushing, part **6**, is shown in a front and a side view, the horizontal center line of which is $6\frac{3}{8}$ inches above the bottom border line. The vertical center lines should be located $7\frac{1}{4}$ inches and $8\frac{1}{4}$ inches, respectively, from the left-hand border line.

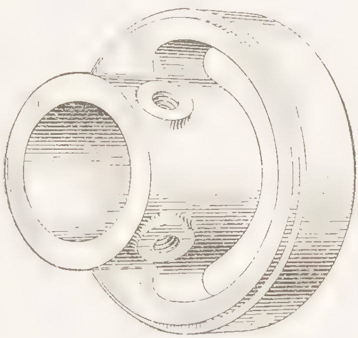


Fig. 6

11. Part **7** is the eccentric sheave, which is fastened to the crank-shaft by means of two setscrews, part **14**, that pass through the tapped holes indicated. Its center is $\frac{7}{8}$ inch to one side of the shaft center, this distance determining the throw of the eccentric and the travel of the valve. A perspective view of this detail is shown in Fig. 6.

On the plate, two views of this part are shown. Draw the horizontal center line of the upper view $4\frac{3}{8}$ inches above the lower border line, and its vertical center line 6 inches from

the right-hand border line, leaving a space of $\frac{1}{2}$ inch between this view and the one below. The center lines of the holes for the setscrews form angles of 45° with the horizontal center line of the sheave.

Parts 8 and 9 are the halves of the eccentric strap which embraces the revolving eccentric sheave. They are prevented from sliding sidewise by the engagement of the central rib on the sheave with a corresponding groove in the strap. Two bolts, part **12,** are inserted through holes in the latter and hold the halves together by means of nuts and check-nuts, part **13.** The lines of intersection between the oil cup and strap, as shown in elevation, are indicated by two curves, the radii of which have not been indicated, as it will suffice if they are drawn approximately. The same remark applies to the intersections shown in the end view. The sectional view shown near the elevation is a section taken through the strap. A perspective view of the eccentric strap is shown in Fig. 7. Locate the center lines of the three views 7 inches, $3\frac{3}{8}$ inches, and $\frac{5}{8}$ inch, respectively, from the right-hand border line and draw the horizontal center line $5\frac{1}{4}$ inches below the upper border line. The nuts and check-nuts, part **13,** required for the bolts, part **12,** are not shown in detail as they are of standard size.

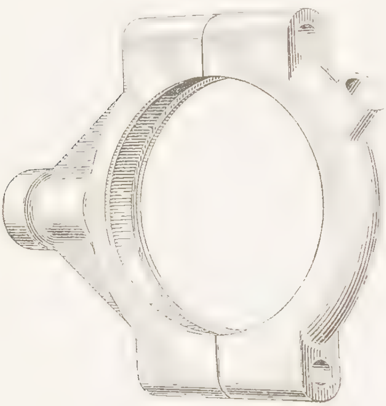
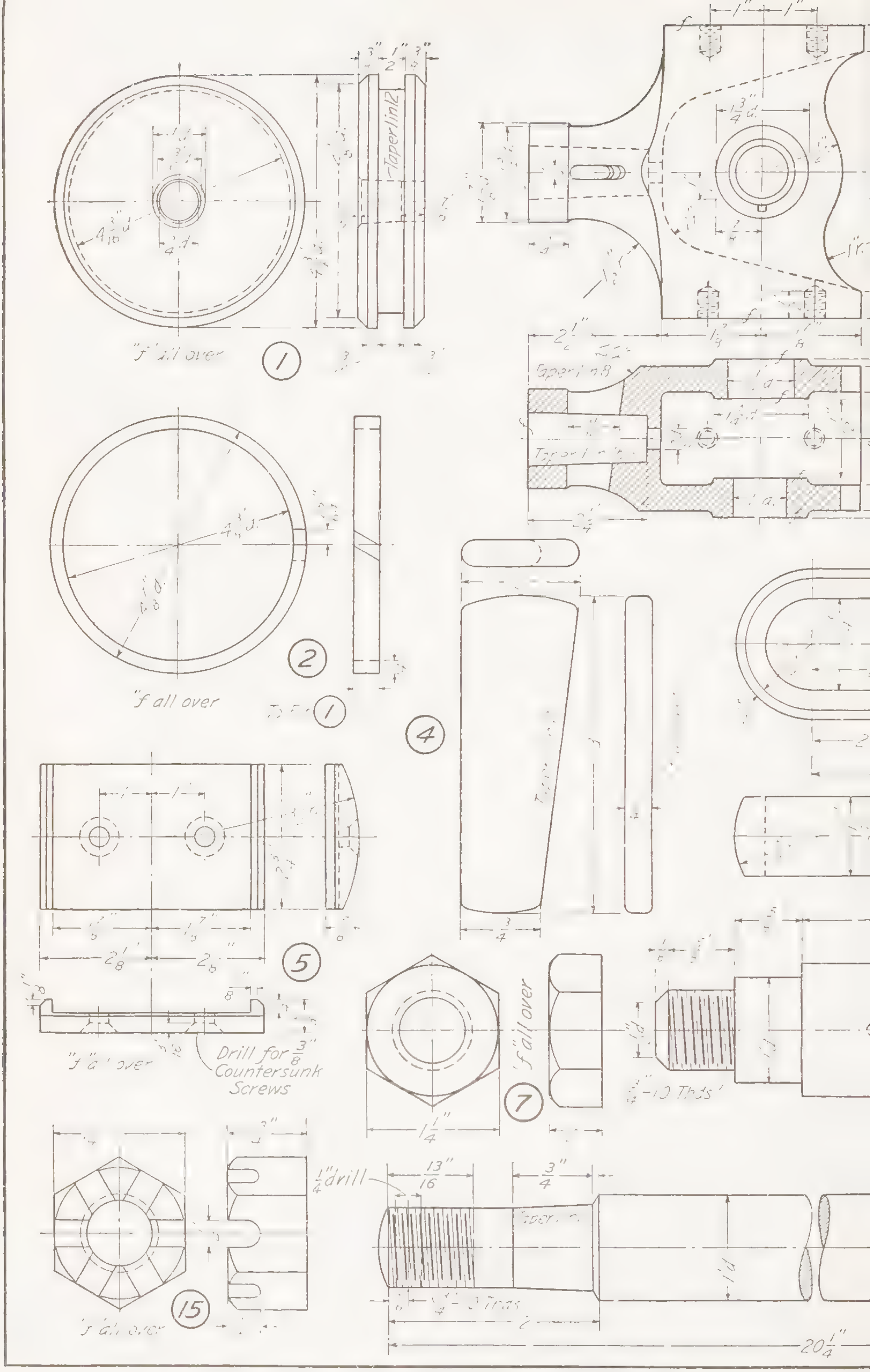


Fig. 7

12. The valve rod, part **2,** is shown in position in the sectional assembly. It has a long-threaded portion on which two nuts together with the check-nuts, part **11,** are screwed to fix the valve in position and by means of which adjustment of the valve may be made. When drawing part **2** in the assembly, locate its center line $1\frac{1}{4}$ inches below the upper border line and



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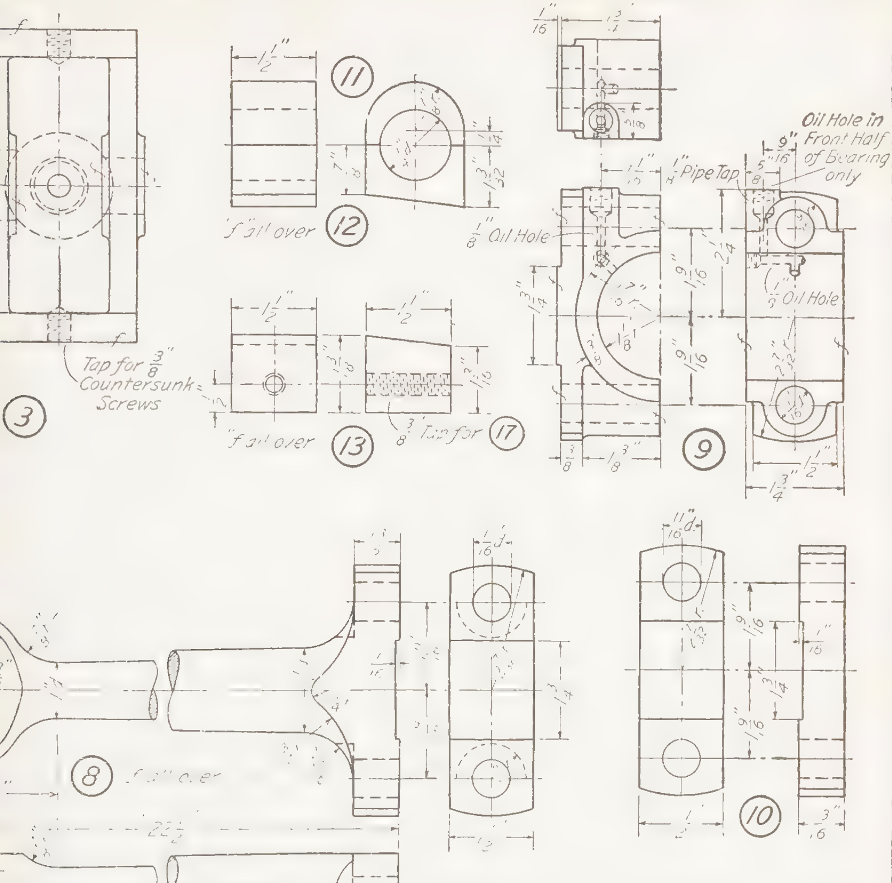
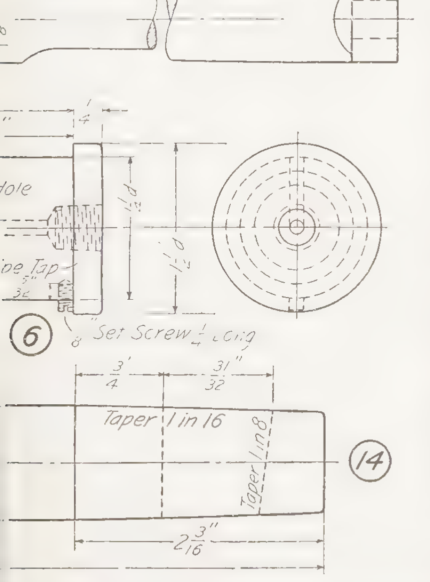




2	$\frac{5}{8}$" Nuts and Lock Nuts	19	Steel		
2	$\frac{5}{8}$" Bolts $6\frac{1}{4}$" Long Thd $1\frac{1}{4}$"	18	Steel		
2	$\frac{3}{8}$" Hex Head Bolts $\frac{7}{8}$" Long Thd $\frac{7}{8}$"	17	Steel		
4	[illegible]	16	Steel		
1	Nut and Cotter Pin for 14	15	Steel		
1	Piston Rod	14	Forged Steel		
1	Wedge for 8	13	Composition Metal	Pattern	H
1	Connecting Rod Bearing	12	Composition Metal	Pattern	G
1	Connecting Rod Bearing	11	Composition Metal	Pattern	F
1	Connecting Rod Strap	10	Steel		
2	Connecting Rod Bearings	9	Composition Metal	Pattern	E
1	Connecting Rod	8	Forged Steel		
1	Nut for 6	7	Steel		
1	Cross Head Pin	6	Steel		
2	Wearing Strips for 3	5	Composition Metal	Pattern	D
1	Key for 3	4	Steel		
1	Cross Head	3	Cast Iron	Pattern	C
1	Piston Ring	2	Cast Iron	Pattern	B
1	Piston	1	Cast Iron	Pattern	A

PISTON, CROSS HEAD AND CONNECTING ROD

DRAWN BY__________

DATE__________

1019

draw the vertical center line of the valve $1\frac{3}{4}$ inches from the left-hand border line. Locate the vertical center line of the shaft $3\frac{13}{16}$ inches from the right-hand border line and complete this view.

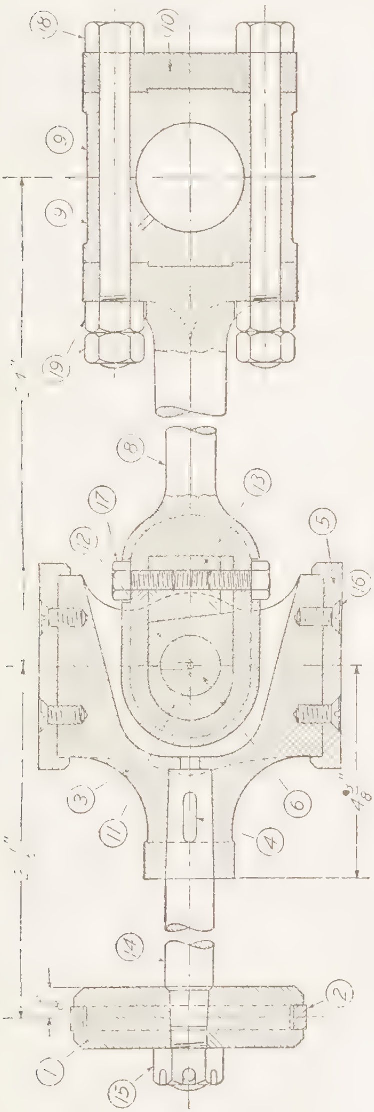


Fig. 8

PLATE 1019, TITLE: PISTON, CROSSHEAD, AND CONNECTING-ROD

13. In the sectional assembly, Fig. 8, is seen the piston, part **1**, which is given a reciprocating motion in the steam cylinder by the steam acting alternately on either side of it. Its motion is conveyed by the piston rod, part **14**, to the crosshead, part **3**, the latter containing in its interior one end of the connecting-rod, part **8**, swinging around a pin, part **6**, while the other end has a bearing, part **9**, that embraces the crankpin. In this manner the force acting on the piston is transmitted to the crankpin, where the reciprocating motion of the piston is changed into a rotary one. All the views on this plate are drawn half size, except those of parts **4**, **6**, **7**, **14**, and **15**, which are drawn full size.

14. The piston, part **1** (see detail numbered **1**), is made of cast iron and is provided on its outer edge with a groove for the piston ring, and with a central hole for the piston rod. The hole is composed of a straight and a tapered part, the straight part extending to a point $\frac{7}{16}$ inch from one end. The diameter of the hole varies from $\frac{3}{4}$ inch to $\frac{13}{16}$ inch, the latter dimension applying to a point $\frac{1}{16}$ inch from end of hole, at which place the hole is countersunk, enlarging the diameter to 1 inch. Locate the horizontal center line of the two views 2 inches from the upper border line, and the vertical center line $1\frac{5}{8}$ inches from the left-hand border line, leaving a space of $\frac{1}{2}$ inch between the two views.

15. The piston ring, part **2,** fits in the groove around the outside of the piston; it provides a steam-tight fit between the piston and the cylinder walls, and is for this reason made expansible by leaving an opening of $\frac{25}{64}$ inch between its ends. It will be noticed that the diameter of the ring is larger than that of the inside of the cylinder; but when sprung into place in the cylinder it will adjust itself to the cylinder bore and the two ends will approach each other, until they nearly touch. The horizontal center line of the two views may be drawn $5\frac{1}{4}$ inches from the upper border line, and the vertical center line of the elevation placed $1\frac{5}{8}$ inches from the left-hand border line; a space of $\frac{7}{16}$ inch is left between these views.

The crown nut, part **15,** fits the end of the piston rod and fastens the piston securely to the latter. To prevent an accidental turning of the nut, it is provided with a series of grooves into which fits a pin, which also passes through a hole in end of the piston rod. The horizontal center line of these views is placed $1\frac{1}{4}$ inches from the lower border line, and the vertical one of the elevation $1\frac{1}{16}$ inches from the left-hand border line, leaving a space of $\frac{3}{8}$ inch between the views.

16. The piston rod, part **14,** is tapered at one end to fit the piston and at the other to fit the crosshead. When the dimension of one end of a tapered piece is given, together with its length, the dimension of the other end of the taper may be found either by calculation or by construction. The method

by calculation is as follows: The taper shown on the plate is 1 in 16, which means that for each inch of length there is a change in diameter of $\frac{1}{16}$ inch. Hence, for a length of $2\frac{3}{16}$ inches, the change will be $\frac{1}{16} \times 2\frac{3}{16} = .137$ inch. The full diameter of the rod is 1 inch, therefore the small end is $1 - .137 = .863$ inch, or nearly $\frac{55}{64}$ inch, in diameter.

If this diameter is to be found by construction, proceed as follows: Multiply the fraction representing the increase or decrease in diameter in 1 inch in length by some convenient length, preferably by some number that will divide the denominator without a remainder; in this case multiply by 4, obtaining $\frac{1}{16} \times 4 = \frac{1}{4}$ inch, which represents the difference in diameters 4 inches apart. Next, at a point 4 inches from where the taper begins, draw a line at right angles to the center line and lay off on each side of it one-half the diameter at that point, or $\frac{1}{2} - (\frac{1}{4} \div 2) = \frac{3}{8}$ inch. Draw straight lines joining the extremities of this diameter with the extremities of the vertical line defining the diameter at the beginning of the taper. From the point where the taper begins, measure back on the center line $2\frac{3}{16}$ inches, the length of the tapered part, and draw through the end point a line perpendicular to the center line. The distance on this end line between the tapering lines is the diameter at this point.

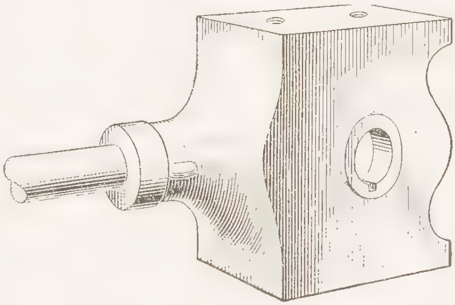


Fig. 9

At the other end of the rod the diameter is $\frac{3}{4}$ inch, and the taper is 1 in 12. This end is to fit the hole in the piston, part **1**, and as the diameters and length of the hole are given in the views of the piston, the tapered part of the piston rod may be drawn by means of these dimensions. Locate the center line of the rod $1\frac{1}{8}$ inches above the lower border line; leave a space of $\frac{5}{8}$ inch between the rod and the side view of nut, part **15**, and make the rod about $8\frac{1}{2}$ inches long.

17. The crosshead, part **3**, shown in perspective in Fig. 9, is fitted to the piston rod by the tapered key, part **4**, which is driven through it and the piston rod, the hole in the piston rod being indicated by dotted lines at the right-hand end, part **14**. The crosshead receives the end of the connecting-rod, which is kept in place by the crosshead pin, part **6**. The upper and lower interior surfaces of the crosshead taper toward the closed end, while the vertical sides are parallel and provided inside and outside with bosses around the holes for the pin. On top and bottom of the head, holes are tapped for the screws that hold the wearing strips, part **5**, in place. Lay off the horizontal center line for the elevation and end view $1\frac{3}{4}$ inches, and that of the sectional plan $4\frac{1}{4}$ inches below the upper border line. Let the vertical center line of the two left-hand views be $7\frac{1}{8}$ inches from the left-hand border line, and place the remaining view $\frac{7}{8}$ inch to the right of the elevation.

18. The connecting-rod, part **8**, is shown broken, the size of the plate not permitting it to be drawn full length. The method employed in laying off the correct taper of the remaining parts is similar to that explained in Art. **16**. The places where the tapered portion of the rod begins and ends are found by drawing verticals through the centers that are used for striking the arcs of the $\frac{7}{8}$-inch-radius fillets at either end; the points of intersection between the verticals and the fillet arcs are the initial points of the tapered part. It is found by calculation that the total length of the tapered part is $16\frac{13}{16}$ inches; with this length and the given diameters at each end, the taper can readily be drawn.

One end of the connecting-rod receives the bearings, parts **11** and **12**, which fit over the crosshead pin, part **6**. For the purpose of lubricating the brasses, part **11**, the crosshead pin, part **6**, is drilled with lubricating holes, and an oil cup is fitted in the $\frac{1}{4}$-inch tapped hole in the end of the pin. The other end of the rod is attached to the crankpin bearings, part **9**, one of which is fitted with an oil cup.

The bearing, parts **11** and **12**, is prevented from moving sidewise along the crosshead pin, because its width is just

equal to the distance between the inside surfaces of the bosses on the crosshead. The two parts of the bearing are forced toward the pin by means of the wedge, part **13**, which may be raised or lowered by turning the adjusting screws, part **17**, in the proper direction. Notice that the holes through which these screws pass are countersunk about $\frac{3}{16}$ inch for the screw heads; hence the two curves in the outer line defining the outline of the small end of the rod in the elevation. Draw the horizontal center line of the elevation and end view of the connecting-rod $6\frac{3}{16}$ inches, and the bottom view 8 inches, below the upper border line. The vertical center line passing through the center of the curved part at the left-hand end is $9\frac{3}{8}$ inches, and the one through the end view is $3\frac{9}{16}$ inches, from the right-hand border line. Make the rod about $5\frac{3}{4}$ inches long.

19. Next draw the crosshead pin, part **6**, with its center line $3\frac{3}{16}$ inches above the lower border line, and the vertical center line of the end view $5\frac{1}{4}$ inches from the right-hand border line, leaving a space of $1\frac{5}{16}$ inch between the two views. Also draw the nut, part **7**, that screws on the threaded end of the pin and fastens it to the crosshead. Use as horizontal center line for the nut that of the pin, produced, and locate the center line of the elevation 4 inches from the left-hand border line. A space of $\frac{1}{2}$ inch is left between the two views. The lower side of the pin is provided with a $\frac{1}{8}$-inch setscrew which fits into a corresponding notch in the crosshead, thus preventing the pin from turning. Both of these views are drawn full size.

Draw the bearings, parts **11** and **12**, and also the wedge, part **13**. The horizontal center line of the first two views should be $1\frac{3}{8}$ inches below the upper border line, and the vertical center line of the right-hand view $4\frac{1}{4}$ inches from the right-hand border line, leaving a space of $\frac{7}{16}$ inch between the two views. In locating the views of the wedge, a horizontal center line is drawn $3\frac{1}{2}$ inches below the upper border line and the vertical center line of the left-hand view $5\frac{1}{2}$ inches from the right-hand border line, leaving a space of $\frac{7}{16}$ inch between the views.

20. The halves of the crankpin bearings, part **9,** are symmetrical except for the oil-cup boss, and only one of them need be shown. One pattern will serve for both halves, as after the right-hand half has been molded the oil-cup boss, which is made detachable, is removed from the pattern and then the other half is molded. Sometimes a note to this effect is made on the drawing.

Locate the horizontal center line of the two elevations $2\frac{7}{8}$ inches below the upper border line, and the vertical center line of the left-hand view $2\frac{1}{16}$ inches from the right-hand border line; leave a space of $\frac{3}{4}$ inch between the views. The horizontal center line of the upper view should be $\frac{7}{8}$ inch below the upper border line.

Draw the connecting-rod strap, part **10.** The bolts, part **18,** pass through this strap and the connecting-rod, and hold the bearings, part **9,** in position by means of nuts, part **19,** and clamp them to the crankpin. Draw the center line of the strap 6 inches below the upper border line and locate the vertical center line $1\frac{7}{8}$ inches from the right-hand border line. Leave a space of $\frac{5}{8}$ inch between the views.

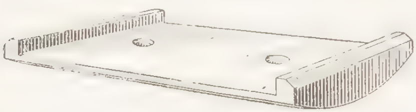
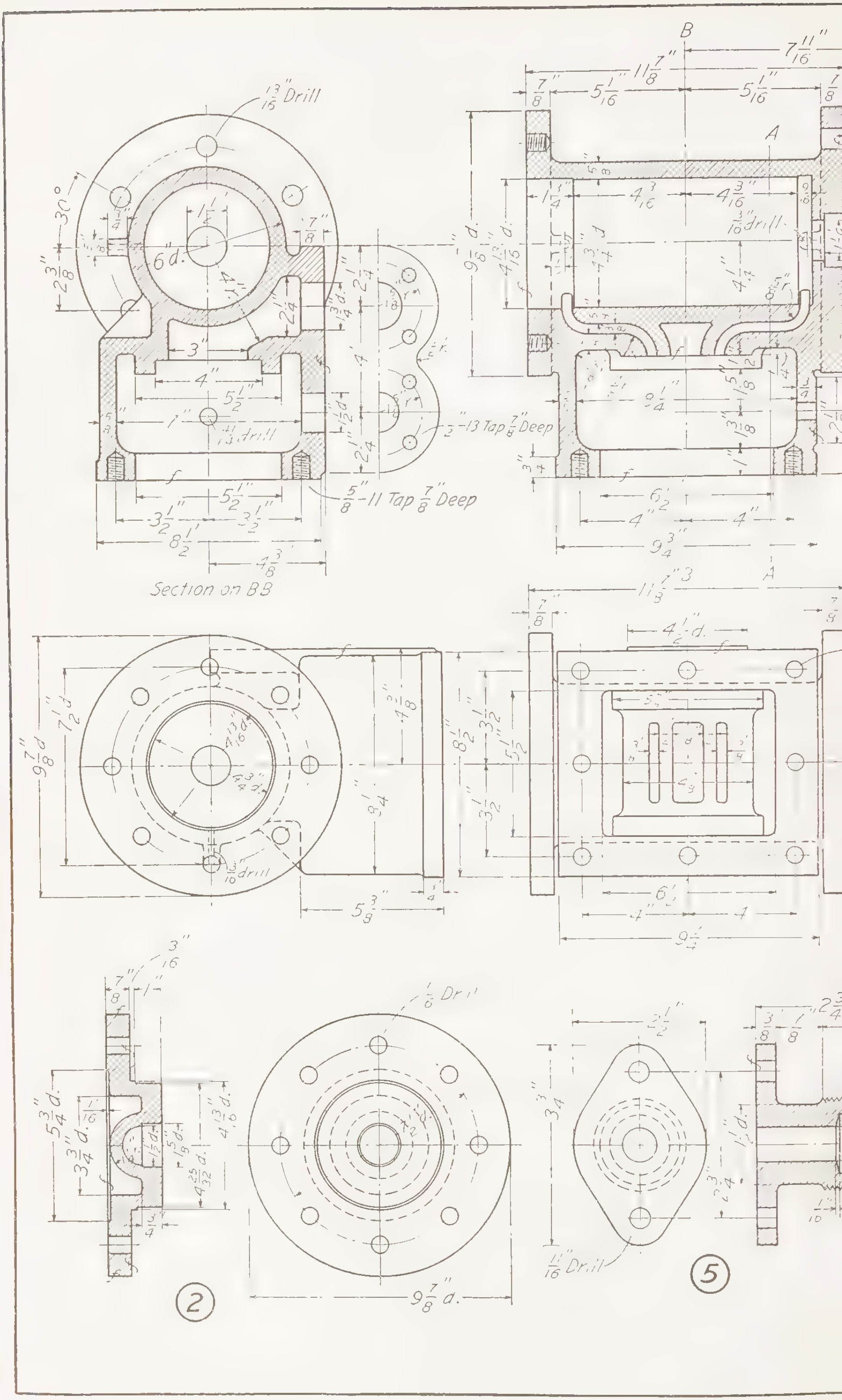


Fig. 10

21. Part **5,** the wearing strip for the crosshead, is shown in three views, and in order to give a clear idea of its true shape a perspective view is shown in Fig. 10. Place the center line of the upper views 5 inches above the lower border line, and let the vertical center line of the plan be $1\frac{3}{8}$ inches from the left-hand border line; leave a space of $\frac{1}{2}$ inch between the two views. Place the third view $\frac{7}{8}$ inch below the plan view.

22. In drawing the detail of the key, part **4,** locate the upper side of the elevation $5\frac{3}{4}$ inches below the upper border line and draw the left-hand edge of the key $4\frac{5}{16}$ inches from the left-hand border line; leave a space of $\frac{3}{8}$ inch between the views. The top view may be placed $\frac{1}{4}$ inch above the others. The taper can be laid off directly from the dimensions. If, however, one of the dimensions, as that marked "$\frac{3}{4}$ inch," had


13/16" Drill
Section on BB
5/8"-11 Tap 7/8" Deep
1/2"-13 Tap 7/8" Deep
3/16" drill
11/16" drill
1/8" Drill
11/16" Drill
2
5

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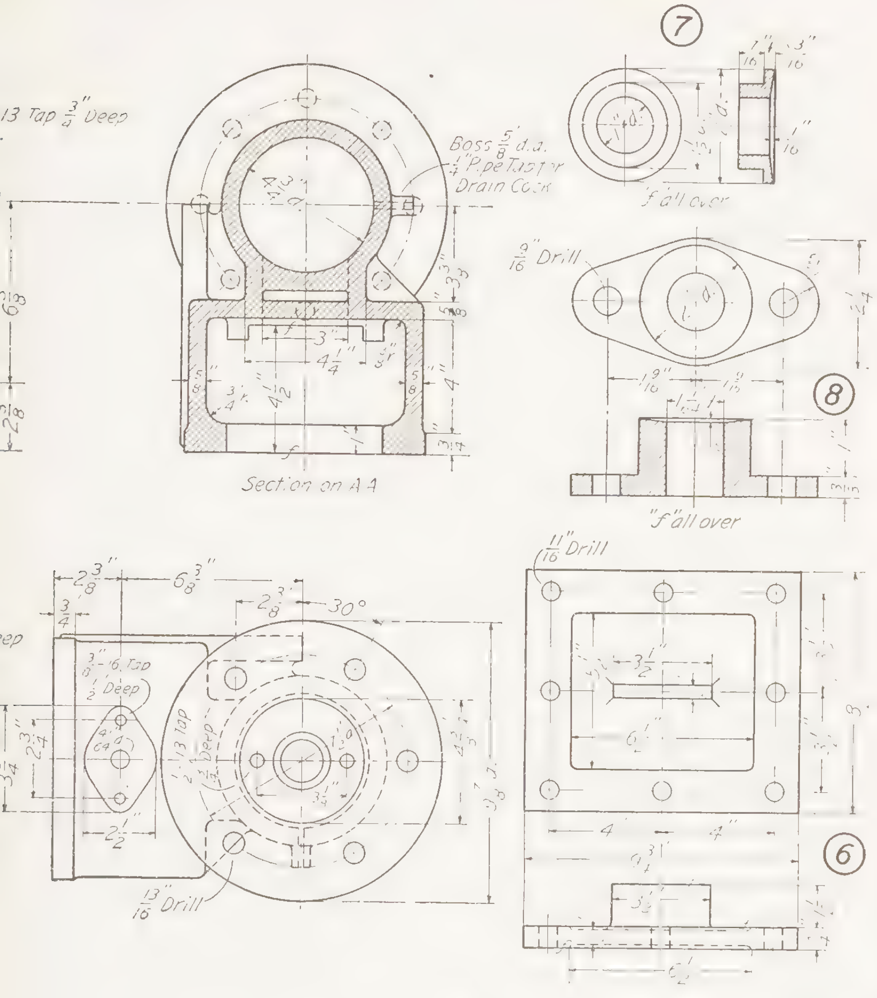

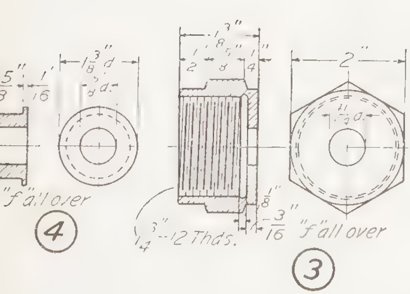

2	Nut and Lock Nut	[illegible]	Steel		
2	Studs [illegible]	11	Steel		
2	Studs Thd. [illegible] Long	10	Steel		
16	Studs Thd. End [illegible] Long	9	Steel		
1	Piston Rod Gland	8	Brass	Pattern	H
1	Bush for Frame End	7	Brass	Pattern	G
1	Steam Chest Cover	6	Cast Iron	Pattern	F
1	Valve Rod Stuffing Box	5	Brass	Pattern	E
1	Gland	4	Brass	Pattern	D
1	Gland Nut	3	Brass	Pattern	C
1	Cylinder Head	2	Cast Iron	Pattern	B
1	Cylinder	1	Cast Iron	Pattern	A

CYLINDER AND VALVE ROD STUFFING BOX

DRAWN BY ________

DATE ________

1020

Name, Class Letters, and Number

been omitted, the extreme left-hand vertical line would be drawn first, next the line whose dimension is marked "$1\frac{1}{8}$ inches" would be laid off and a perpendicular drawn downwards through its right-hand extremity, and the length of the lower side would be found in the following manner:

A taper of 1 in 8 is equal to $\frac{3}{8}$ inch in 3 inches; hence, lay off 3 inches downwards on the perpendicular last drawn, draw a horizontal line through the point just laid off, and measure off to the left of this point $\frac{3}{8}$ inch; the point so determined is the other extreme point of the taper.

PLATE 1020, TITLE:
CYLINDER AND VALVE-ROD STUFFINGBOX

23. On Plate 1020 are given six views of the engine cylinder, part **1**; and similar views, some of which bear reference letters, are shown in Fig. 11. In the row of views in the center of the plate, the one at the left is an end view of the cylinder, looking toward the crank-shaft, next is a front elevation, and then an end view looking toward the cylinder from the crankshaft. A perspective view of the cylinder is shown in Fig. 12 and should be studied in connection with the front elevation shown in Fig. 11 (*c*). Above the front elevation, in Fig. 11 and likewise on the plate, there is a sectional plan, view (*b*), taken along the horizontal center line, and on either side of this view there are sectional views taken on the lines *A–A* and *B–B* of the sectional plan. The cylinder is of cast iron, hollowed or cored out to form the cylinder bore, the steam and exhaust ports, the steam chest, etc. There is a boxlike extension on one side of the cylinder, called the steam chest, which is provided with bosses to which the flanges of the steam and exhaust pipes are fastened.

24. In Fig. 11, which represents the pencil drawing of the six views shown in Plate 1020, the sectional plan is also made to serve as an assembly, the various parts situated in or on the cylinder being indicated by means of dotted lines. These lines are not to be reproduced on the plate, as they are inserted

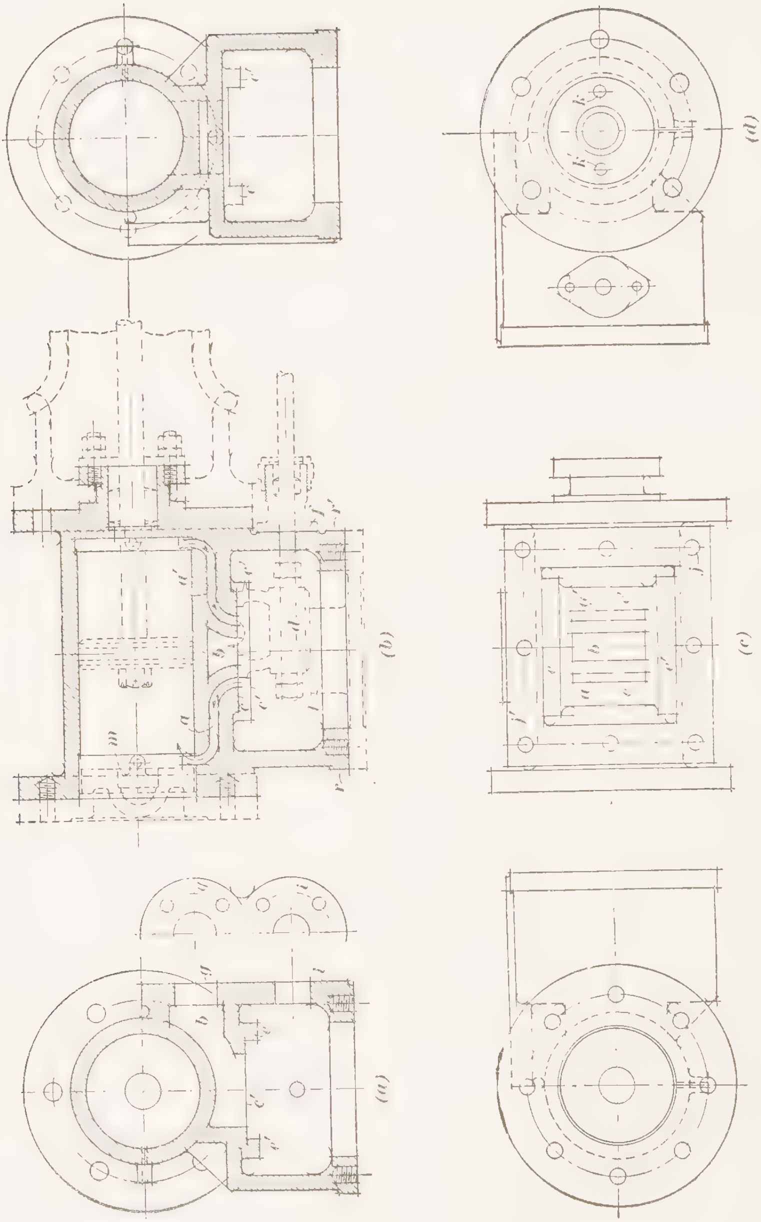

Fig. 11

merely to aid in giving an understanding of the relations between the various parts.

The steam pipe is fastened by studs to the flange *i* shown in Fig. 11. (*a*). The steam enters the steam chest through this pipe and passes from here through either of the ports *a*, *a′*, Fig. 11 (*b*), into one end of the cylinder, the valve *d* determining by its position through which of the ports the steam shall enter and how long its flow is to continue. In the position shown in view (*b*), the steam has entered through port *a*, driving the piston to the right. The steam that at the previous stroke has been acting on the right side of the piston is now escaping through port *a′* into the valve *d* and out through the exhaust port *b* into the exhaust pipe, which is bolted to the steam chest at *g*, Fig. 11 (*a*). The manner in which valve *d* receives its motion has already been described in connection with Plate 1018. Parts **1**, **2**, and **6** are to be drawn to a scale of 3 inches = 1 foot; parts **3**, **4**, **5**, **7**, and **8**, to a scale of 6 inches = 1 foot.

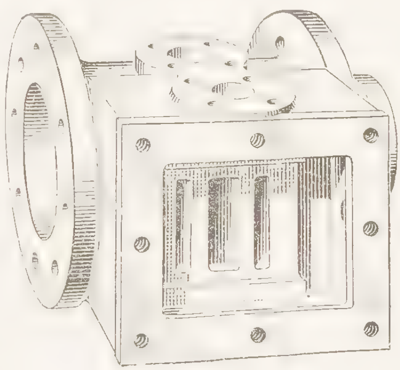

Fig. 12

25. The sectional plan view is to be drawn first and located on a horizontal center line $2\frac{3}{16}$ inches below the upper border line; draw its vertical center line $6\frac{3}{4}$ inches from the left-hand border line. The bore of the cylinder is $4\frac{3}{4}$ inches for $8\frac{3}{8}$ inches of its length and is enlarged to $4\frac{13}{16}$ inches at a distance of $1\frac{3}{4}$ inches from the open end and $\frac{9}{16}$ inch from the closed end. The walls are $\frac{5}{8}$ inch thick and the flanges at each end are $\frac{7}{8}$ inch thick and $9\frac{7}{8}$ inches in diameter.

In fixing the length of the cylinders, provision must be made for sufficient clearance between the piston and the covers at the ends of the cylinders; that is, the piston must have room to complete its stroke of 8 inches and leave a space at each

end of $\frac{1}{8}$ inch to $\frac{1}{4}$ inch for clearance. Drain-valve bosses are provided at each end of the cylinder. These bosses are drilled and tapped to receive the drain valves by means of which the cylinder may be emptied of any accumulated water. These drain valves are not shown.

In Fig. 11 (*b*) the valve seat $c\,c'$ on which the valve travels is located in the steam chest $4\frac{1}{4}$ inches from the center line of the cylinder. The center line of the valve stem is $6\frac{3}{8}$ inches from the center of the cylinder. The valve is prevented from moving sidewise by two ribs e, e', $\frac{1}{2}$ inch high and $5\frac{5}{8}$ inches long. One of these is shown at e', Fig. 11 (*b*), and both are shown in section at e, e' in view (*a*), and they are shown in plan in view (*c*).

26. The exhaust port *b*, Fig. 11, is $1\frac{1}{8}$ inches wide and separated from the steam ports by webs $\frac{1}{2}$ inch thick. It follows a path, for a short distance, around the upper part of the cylinder and has walls $\frac{5}{8}$ inch thick. The steam ports have a $\frac{3}{8}$-inch opening 3 inches wide, and follow a curved path through the walls of the cylinder. The straight parts of these ports are centrally located in the cylinder walls and are joined to the ends of the ports by curves having their centers in the valve seat and the cylinder bore, respectively. The steam-chest walls are $\frac{5}{8}$ inch thick, with an extension of $\frac{1}{8}$ inch at *r* and *r'* to permit a machine finish to match the steam-chest cover. At *f* is a boss of equal thickness to be finished as a seat for the valve-stem stuffingbox, an opening being provided for the valve rod $\frac{41}{64}$ inch in diameter. In the front of the steam chest is an opening $6\frac{1}{2}$ inches $\times\, 5\frac{1}{2}$ inches.

Dimensions for locating the stud holes in the cylinder flange for the cover are found on the drawing of part 2, and the distance between the stud holes in the steam-chest flange is found on the elevation of the steam chest.

On the plate the outer part of the stuffingbox is shown turned to $4\frac{3}{8}$ inches diameter to fit into a corresponding recess in the end of the frame. This construction provides for a central position of the cylinder in relation to the center line of the frame.

27. The two cross-sections are to be drawn next, the vertical center line of the section on *B B* being $1\frac{7}{8}$ inches from the left-hand border line. In this view are clearly shown the bore of the cylinder, the thickness of walls, the valve seat, and the ribs *e e′*, Fig. 11. Both cross-sections are located on the extended center line of the horizontal section.

The flange faces at the inlet and exhaust ports are drawn to the right of Section *B B*, on a vertical center line $3\frac{1}{2}$ inches from the left-hand border line, and the horizontal centers are projected from Section *B B*.

The vertical center line of the Section on *A A* is $5\frac{5}{16}$ inches from the right-hand border line.

28. The elevation and end views, shown in the central part of the plate, all have a common horizontal center line 7 inches below the upper border line. Beginning with the view at the right, which shows the cylinder as viewed from the stuffing-box end, locate its vertical center line $5\frac{5}{16}$ inches from the right-hand border line. The cylinder flange shown in this view is made to fit against a corresponding flange at the end of the frame, the spacing of the studs being the same in both flanges. It will be noticed that, owing to the projecting parts of the steam chest, these studs cannot be arranged all around the flange, but as the joint is not required to be steam-tight, this end of the cylinder being cast solid, there is no objection to the unequal spacing.

As the elevation of the steam chest is placed on the same vertical center line as the horizontal section above, the longitudinal dimensions may be projected directly from the latter view. In this view of the steam chest are shown the steam and exhaust ports, the valve seat, and the ribs *e e′* shown in Fig. 11. The drilling plan for the eight studs, over which the steam-chest cover fits, is shown at *j j′*, Fig. 11 (*c*), and in Fig. 11 (*d*) is shown the locations of the holes *k k′* which receive the two studs; this view also shows the frame and the drilling plan. The locations of the holes correspond with the positions of the studs that are tapped into the engine frame and support the cylinder.

29. The steam-chest cover, part **6,** is next drawn in elevation and plan view. Locate the vertical center line of these views $2\frac{1}{8}$ inches from the right-hand border line, and the horizontal center line of the plan $6\frac{7}{16}$ inches below the upper border line, leaving a space of $\frac{5}{8}$ inch between the views. The projection *l,* Fig. **11** (*b*), holds the valve in place and prevents any tendency to tilt. The cover is recessed inside and out to obviate the necessity of finishing any parts except those that fit the steam chest and those on which the nuts and studs are seated.

30. The views of parts **2, 3, 4,** and **5** are all on a horizontal center line $2\frac{5}{16}$ inches above the bottom border line.

Part **2** is the cylinder head, which is bolted to the cylinder by means of the eight studs, part **9,** which are screwed into the end of the cylinder before the cylinder head is put in place. As shown in Fig. **11** (*b*), at *m* is a recess in the cylinder cover to make room for the nut on the end of the piston rod when the piston is at the head end of the cylinder.

31. Locate the end view of part **5,** the valve-rod stuffingbox, at a distance of $5\frac{7}{8}$ inches from the left-hand border line, leaving a space of $\frac{1}{2}$ inch between it and the sectional view. The stuffingbox is bolted to the steam chest at *f*, Fig. **11** (*b*), by means of studs, part **10.**

Part **4** is the gland that compresses and holds the packing in place in the stuffingbox, the purpose of the packing being to make the fit between piston rod and stuffingbox steam-tight. It should be noticed that those surfaces of the stuffingbox and the gland that face each other are countersunk, the object being to force the packing toward the piston rod. Locate the vertical center line of the elevation $7\frac{1}{16}$ inches from the right-hand border line and leave a space of $\frac{1}{4}$ inch between the two views.

Part **3** is the clamping nut that holds the gland, part **4,** in position and by means of which it may be forced against the packing. Let the center line of the right-hand view be 4[illegible] inches from the right-hand border line and leave a space of $\frac{1}{4}$ inch between the two views.

32. The remaining parts **7** and **8** belong to the piston-rod stuffingbox, part **7** being a bushing inserted in the end of the

ASSEMBLY DRAWING OF
STEAM ENGINE

DRAWN BY_ _ _ _ _ _ _ _ _ _ _ _ _
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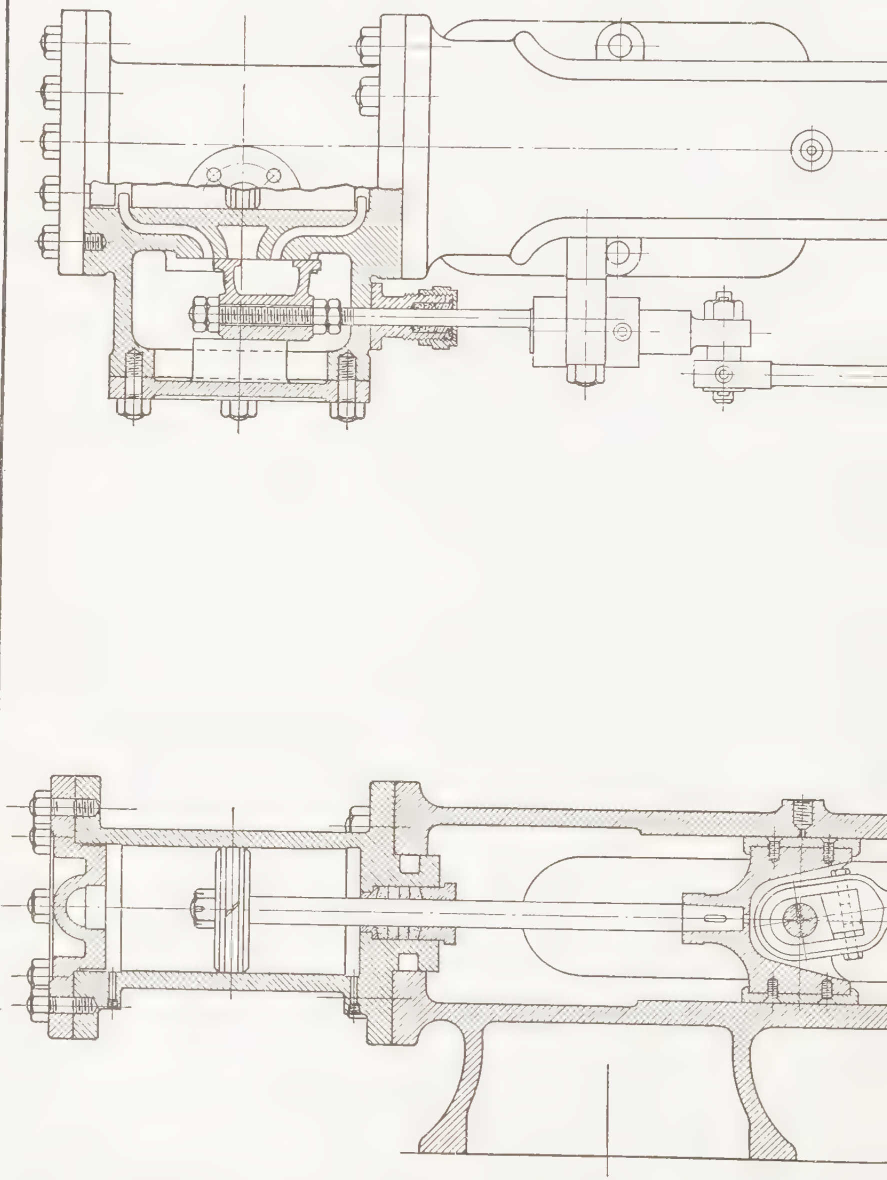
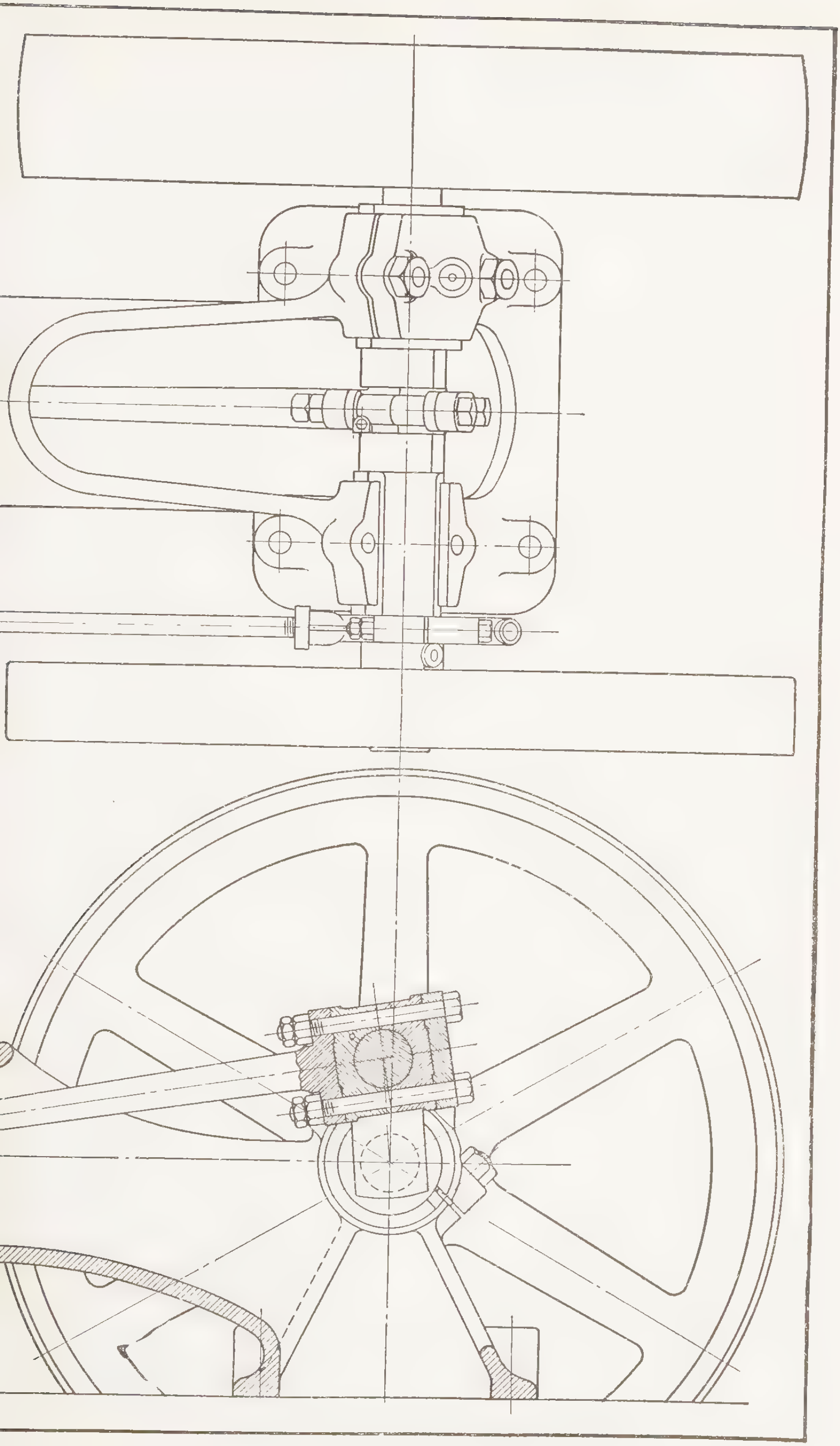




stuffingbox and part **8** the gland that holds the packing in position and forces it inwards by means of the nuts, part **12**, and studs, part **11**.

Place the views of the gland, part **8**, on a vertical center line $1\frac{7}{8}$ inches from the right-hand border line and let the horizontal center line of the upper view be 3 inches from the upper border line, leaving a space of $\frac{7}{16}$ inch between the views.

The horizontal center line for the views of part **7** is $1\frac{7}{16}$ inches below the upper border line and the center line of the elevation is $2\frac{1}{2}$ inches from the right-hand border line. The views are spaced $\frac{1}{2}$ inch apart.

PLATE 1021, TITLE: ASSEMBLY DRAWING OF HORIZONTAL STEAM ENGINE

33. From the details given on Plates 1016 to 1020, inclusive, an assembly drawing is to be made that will show a plan of the engine, partly in section, and also a sectional elevation.

To give a general idea of what the assembly drawing will contain, a reduced copy of the plate is given in Fig. 13 in which all dotted lines indicating parts not visible have been omitted so as to simplify the work. In order to make the drawing to the same scale as used in the principal views on the preceding plates, it is necessary to increase the border lines to $13\frac{1}{2}\times17\frac{1}{2}$ inches and to locate the title of the plate in the upper left-hand corner. The perspective drawing of the steam engine shown in Fig. 14 will prove helpful as a guide to the relative positions of the various details.

34. In practice, an assembly drawing is generally made before the details are laid out, the main dimensions of the latter being derived from the assembly. While the details are being worked out, it will often be found necessary to change the dimensions of some part, which in turn will require the readjustment of the dimensions of adjoining parts. After all the detail dimensions have been finally established, the assembly will be altered so as to show the details with their correct dimensions and in their correct positions. In the present case

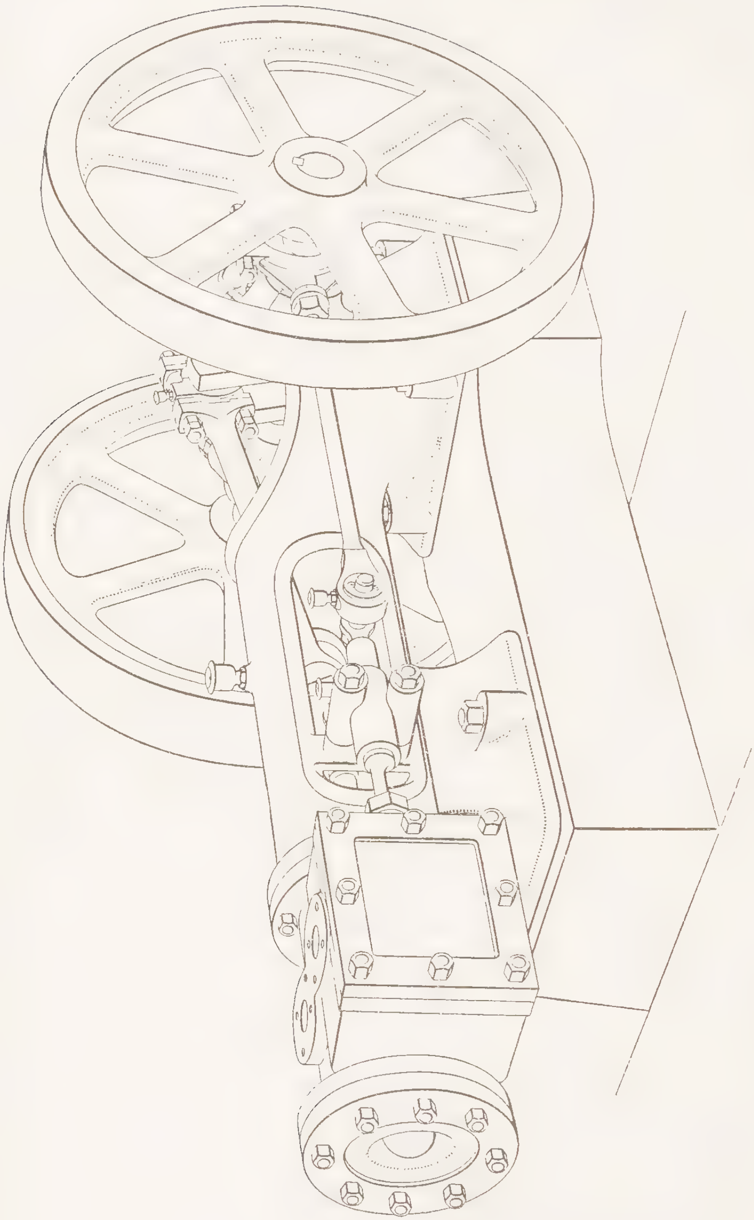


Fig. 14

it has to be assumed that the general assembly was made before the work on the details was started and that Plate 1021 is to represent the details in their final form. This combining of the details into one drawing will serve as a check on the accuracy of the detail dimensions, and on the practicability of the design. For instance, the drawing may show that at certain points an insufficient amount of clearance has been left for some moving part, or that it is impossible to insert some of the bolts for fastening certain parts together, or that a piece will not serve for both sides of a machine, but has to be made left and right, and so on. Points such as these may easily be overlooked in detail drawings.

35. Commence the drawing by laying off the true horizontal center lines $3\frac{3}{4}$ inches and $10\frac{15}{16}$ inches, respectively,

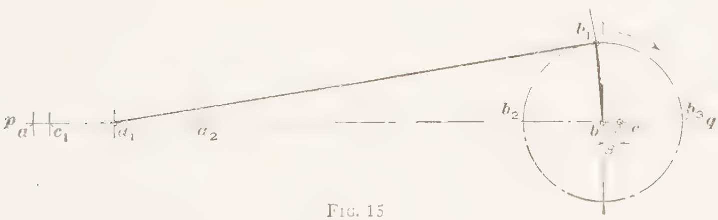


FIG. 15

from the upper border line, and draw the vertical center line through center of the crank-shaft 4 inches from the right-hand border line. Draw the end of the cylinder at a distance from the crank-shaft center corresponding to that given on the engine-frame drawing. Next draw the frame in both views with bearings, studs, nuts, and holes for foundation bolts.

36. On the elevation, draw the piston in its middle position, together with the piston rod and crosshead. The method by which to determine the corresponding position of the center of the crankpin is shown in Fig. 15, where b on the engine center line $p\ q$ represents the center of the crank-shaft and $b\ b_1$ the distance between the centers of shaft and crankpin, and $b_2\ b_3$ the two dead centers of the engine. To find the position of the center of the crosshead pin while the piston occupies its middle position, use b as a center; then with a radius

equal to the length of the connecting-rod between its centers, draw a small arc intersecting the line $p\,q$ at a_1. Set off points a and a_2 at either side of a_1 at distances equal to $b\,b_2$; then the length of stroke is indicated by the distance $a\,a_2$. To find the position of the crankpin corresponding to the middle position of the piston, draw the circle $b_2\,b_3$ with $b\,b_1$

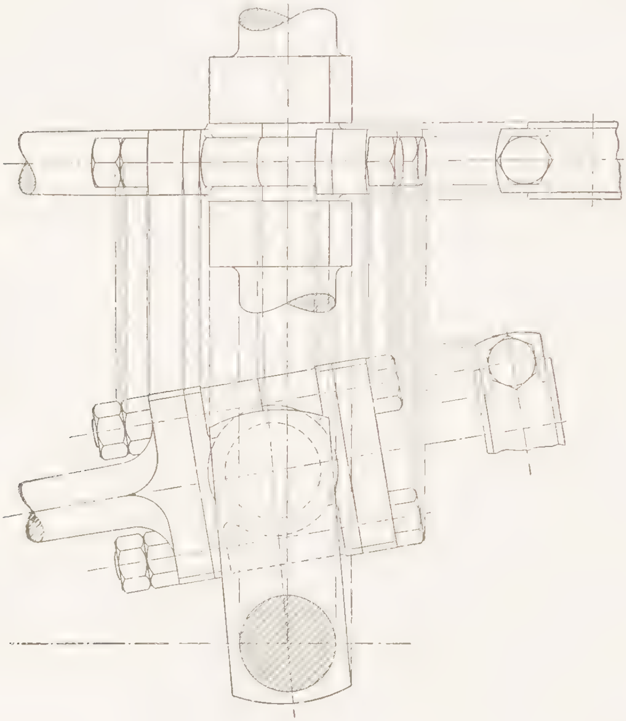


FIG. 16

as a radius. Then, with a radius equal to $a_1\,b$ and with a_1 as a center, draw the arc $b\,b_1$. The point of intersection b_1 with the circle $b_2\,b_3$ will be the desired point; namely, the center of the crankpin when the center of the crosshead pin is at a_1. A line connecting a_1 and b_1 will be the center line of the connecting-rod.

37. Complete the connecting-rod in both views, and draw both views of the cylinder with the nuts and the part of the

flange for the steam and exhaust pipes in their proper position, obtaining all dimensions from the detail sketches.

Draw the center line of the valve stem in the plan view, and draw the stuffingbox, valve stem, valve-stem slide and its guide in both views. In order to determine the position of the valve-stem slide, it is necessary to locate the center of the eccentric. In the sectional plan of the assembly, Plate 1021, it is seen that the eccentric is on the dead center farthest from the cylinder. The offset of the eccentric is given as $\frac{7}{8}$ inch in the detail drawing; hence, when in this position, the center of the eccentric strap will be situated at *c*, Fig. 15, $\frac{7}{8}$ inch to the right of the crank-shaft center on the line $p\,q$. With this point as a center, and a radius equal to the distance between the centers of the eccentric strap and the hole in the stud end of the eccentric rod (see detail drawing), in this case 2 feet 4 inches, describe an arc cutting the center line $p\,q$ in c_1; c_1 will be the center of the pin that connects valve rod to the connecting-rod, which may be completed with the aid of the detail drawing. Complete the drawing of the eccentric, eccentric strap, and eccentric rod in both views. Fig. 15 shows by the arrow the direction in which the shaft revolves, this fact being deduced from the position of the eccentric relative to the crank. If the center of the eccentric is moved through an angle of 180°, the crank remaining in its present position, then the motion of the engine would be in the opposite direction.

In Fig. 16 is shown the method of projecting the edges and foreshortened surfaces of the crank-shaft and connecting-rod from the elevation to the plan view.

Finally draw in the bandwheel and flywheel (see general drawing for position). The flywheel will be of the same diameter as the bandwheel, but only 3 inches wide.

READING A WORKING DRAWING

38. The following general method of procedure has, by experience, been shown to be conducive to the accurate and rapid reading of a drawing made in projection. *First,* if the drawing is dimensioned, ignore the existence of the dimension lines and dimensions entirely until after the general shape of the object is fixed on the mind. *Second,* by referring to the several views, form an idea of the shape of the main body of the object; that is, observe if its outline shows it to be a cube, a sphere, a cylinder, a cone, a pyramid, etc., or a combination of several of these elementary forms. The shape of the main body having been impressed on the mind, observe how it is modified by details, determining, by reference to the several views, whether they project from the main body or are recesses, or holes. *Finally,* by referring to the dimensions, form an idea of the relative sizes of the component parts. Pay due regard to all conventional representations that may have been used; for instance, do not become confused if the arm of a pulley, or a rib, which, truly speaking, should have been in section, is shown in full. If two half sections are placed on either side of a common center line, remember that each half must usually be viewed independently of the other and must be mentally completed.

39. When reading a drawing in which the views are correctly placed, it is often a great aid, when the shape of some part is doubtful, to project with a straightedge points or edges of it over to another view, in order to find the location of a corresponding part. When the views are not placed in their correct relative positions, this cannot be done, and in reading a drawing with the views thus placed, the reader is supposed constantly to imagine that the views are in their correct relative positions.

To illustrate the method of reading a working drawing, three mechanical drawings and a perspective view of parts of a lathe are given. Fig. 17 is a drawing of a tailstock casting,

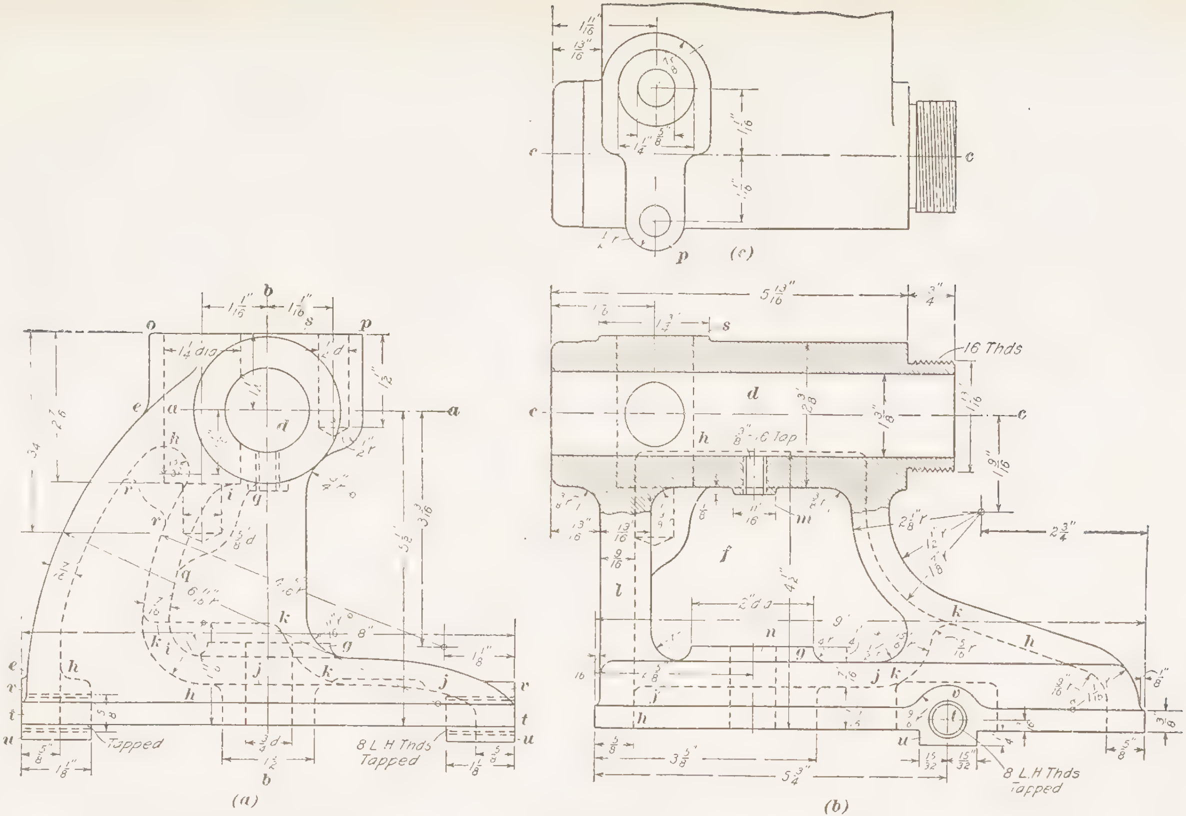

(a)
(b)
(c)
16 Thds
8 L.H Thds Tapped
8 L.H Thds Tapped
Tapped
$\frac{3}{8}$" -16 Tap
$5\frac{13}{16}$"
$5\frac{3}{4}$"
$3\frac{5}{8}$"
$2\frac{3}{4}$"
$4\frac{1}{2}$"
$1\frac{1}{4}$ dia

Fig. 17

which should be studied in connection with the perspective view of a tailstock, Fig. 18, and the general drawing, Fig. 19; and Fig. 20 is a drawing of a headstock. Lathes of a model similar to the one represented by these views are found in most machine shops, and where possible to do so it will be an aid to understanding to compare the drawings with the objects themselves and note the relations of the various details.

40. Tailstock Casting.—The views of the tailstock casting shown in Fig. 17 are an end elevation, view (*a*); a front elevation partly in section, view (*b*), and a plan, or top view, of the barrel, view (*c*). The main center lines *a a*, *b b*, and *c c* pass through the center of the $1\frac{3}{8}$-inch hole *d* bored in the barrel to receive the spindle, and from these lines the principal dimensions are laid off. The body is of irregular shape, being curved at the back, as indicated by the line *e e*, and a recess *f* is formed beneath the middle of the barrel to receive the nut by which the tailstock is clamped to the bed of the lathe.

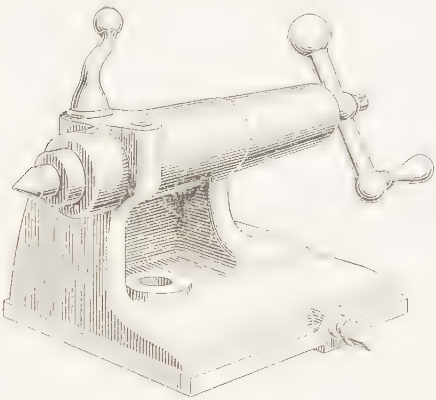
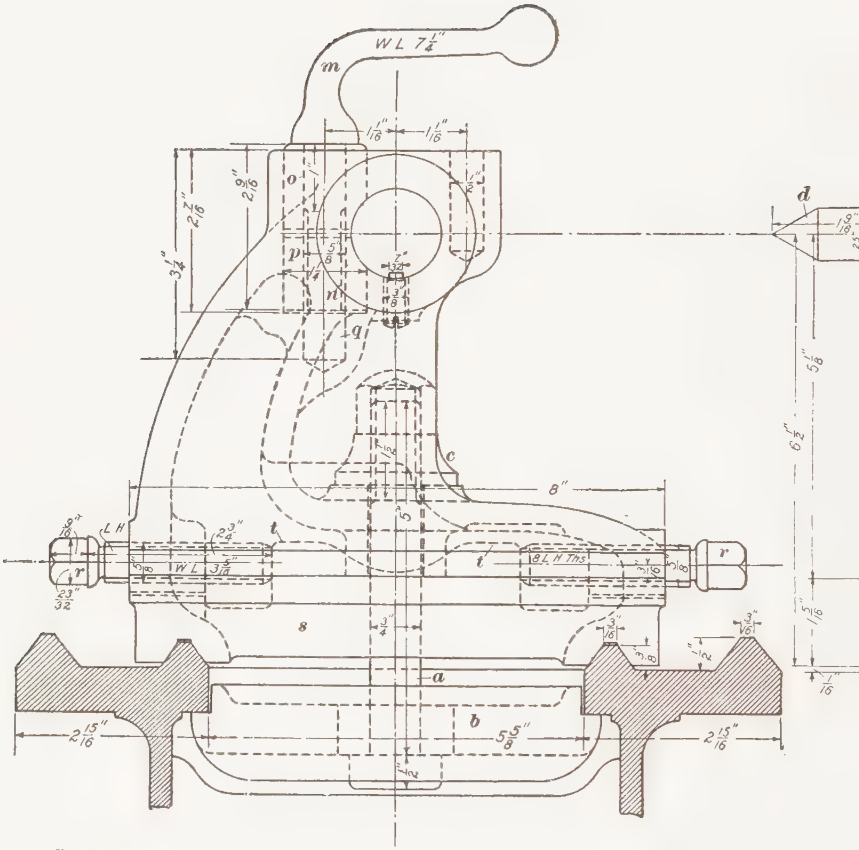
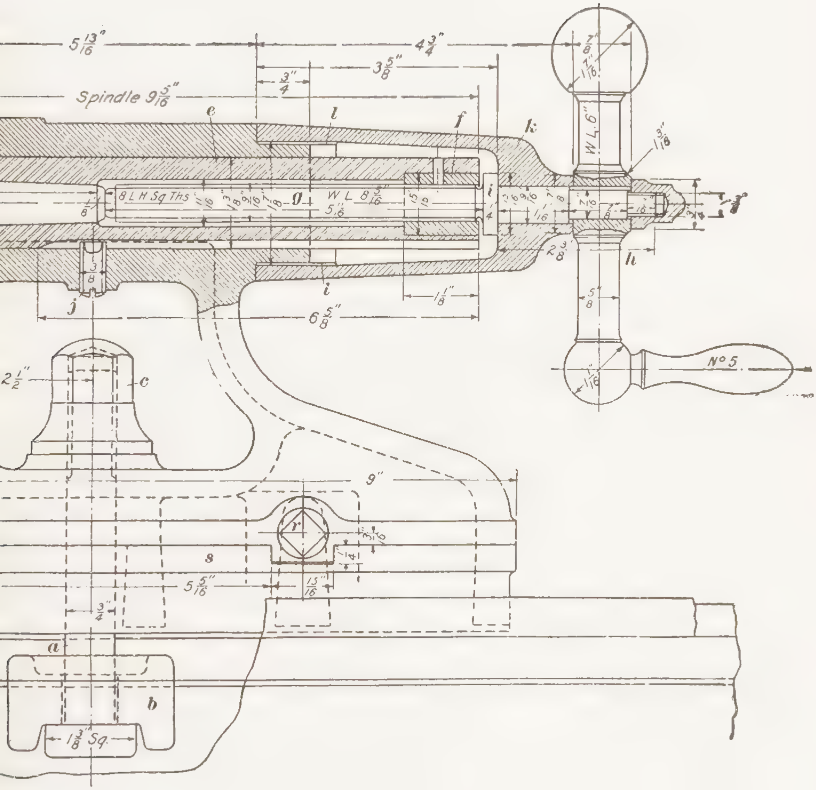


Fig. 18

This nut rests on the top of a boss *g* on the lower surface of the recess. Between the back *e e* and the recess *f* there is an opening cored out inside the casting, as is indicated by the dotted line *h h h*. The back surface of the recess *f* is denoted by the dotted line *i i*, and the thickness of metal between the recess and the cored opening is $\frac{7}{16}$ inch, as marked; also, the thickness of the metal at the back is $\frac{7}{16}$ inch. Beneath the boss *g* the metal is cored out as indicated by the line *j j*, and beyond the recess the cored part is carried higher, as shown by the dotted line *k k*. The barrel is thus supported by a number of metal webs, or walls, varying from $\frac{7}{16}$ to $\frac{5}{8}$ inch in thickness.


WL 7¼"
8"
5⅛"
6½"
8 L H Ths
LH
WL



Spindle 9 5/16"
8 L H Sq Ths
W L 8 5/16"
W L 6"
N° 5
1 3/8" Sq.

41. The barrel has an over-all length of $5\frac{13}{16}$ inches, as shown in Fig. 17 (*b*), and at the end it is turned down for a distance of $\frac{3}{4}$ inch to a diameter of $1\frac{13}{16}$ inches. On this part is cut a screw thread with 16 threads per inch. The opposite end of the barrel overhangs the supporting web *l* by $\frac{13}{16}$ inch. A hole *m* for a setscrew is drilled in the bottom of the barrel, on a line with the center of the hole *n* for the anchor bolt. The hole *m* is threaded with a $\frac{3}{8}$-inch tap having 16 threads per inch, and the threads are indicated by the double lines at each side of the hole. The threads are understood to be United States standard threads, as no definite note is given to state their shape. The slightly elliptical hole shown in the left-hand end of the barrel in view (*b*) is the intersection between the bore in the barrel and the $1\frac{1}{4}$-inch counterbore behind it.

A top view, or plan, of the barrel is shown in (*c*). Two bosses *o* and *p* are formed at opposite sides, on the same center line, which is $1\frac{11}{16}$ inches from the end of the barrel, and the center of each is $1\frac{1}{16}$ inches from the center line *c c*. At the center of the boss *o*, a $\frac{5}{8}$-inch hole is first drilled to a depth of $3\frac{1}{4}$ inches, and this is then counterbored $1\frac{1}{4}$ inches in diameter to a depth of $2\frac{7}{16}$ inches. As these holes would extend through into the cored spaces, metal is added, as shown in view (*b*) and also by the dotted lines *q q* and *r r*, view (*a*), beneath the holes. The boss *p*, view (*c*), has a $\frac{1}{2}$-inch hole drilled at its center to a depth of $1\frac{1}{2}$ inches. The surface *s* of these bosses is faced off so as to be $1\frac{1}{4}$ inches above the center line *c c*.

42. The base of the tailstock casting, Fig. 17, has a length of 9 inches and a width of 8 inches, and projects slightly beyond the unfinished casting all around. The vertical faces of this projecting part of the base are all finished. Two holes *t* are tapped through the base at the sides with 8 left-hand threads per inch. The center of these holes is located $5\frac{3}{4}$ inches from the heavy end of the casting and $\frac{3}{16}$ inch above the lower surface. There is a lug *u* beneath each of the holes *t*, extending $\frac{1}{4}$ inch below the lower surface and $\frac{13}{32}$ inch on either side of the center line through the hole. Each lug is $1\frac{1}{8}$ inches long and is finished on the sides and the bottom. A raised part *v*

having a radius of $\frac{9}{16}$ inch is formed above each hole *t* to give enough metal around the hole. The radii of the several curved surfaces of the casting, and the centers from which the curves are drawn, are clearly indicated.

43. General Drawing of Tailstock.—A general drawing of a tailstock is shown in Fig. 19. This is the same tailstock casting that is shown in Fig. 17, with the addition of all the parts that are attached to it and a part of the lathe bed on which it is clamped. The anchor bolt *a*, Fig. 19, passes up through a slot in the yoke *b* and is fitted with a cap nut *c* that rests on a boss on the casting. When the nut *c* is screwed down, the yoke is drawn up against the bed and the tailstock is firmly held on the **V**'s. The dead center *d* is held in a steel spindle *e* that fits inside the bored barrel of the casting. A nut *f* is pinned to the end of the spindle, and through it passes the screw *g*, to the outer end of which is fixed the handle *h*. The collar *i* and the hub of the handle *h* prevent the screw from moving endwise, and when it is turned by the handle the spindle *e* is moved out of or into the barrel, thus moving the dead center. The spindle *e* has a keyway along its under side, in which fits the flatted end of the setscrew *j*. The spindle is thus prevented from turning, but is free to be moved endwise. The part *k* that carries the screw *g* is threaded inside and is screwed tightly on the threaded end of the barrel, the threads being indicated by the pairs of parallel lines *l*. The thread on the screw *g* is left-hand, so that, when the handle is turned right-handed, the dead center will be moved outwards, away from the tailstock.

44. When the spindle *e*, Fig. 19, has been moved outwards as far as it should go, it may be locked in position by turning the handle *m*. This handle has a threaded stem *n* that passes through the collar *o* and the nut *p* and fits into the drilled hole *q*. Both the collar *o* and the nut *p* are in place when the barrel is bored, and they are cut away at one side to the curve of the spindle. When the handle *m* is turned in the proper direction, the nut *p* is drawn upwards and the collar *o* is forced downwards, and the spindle is clamped firmly between

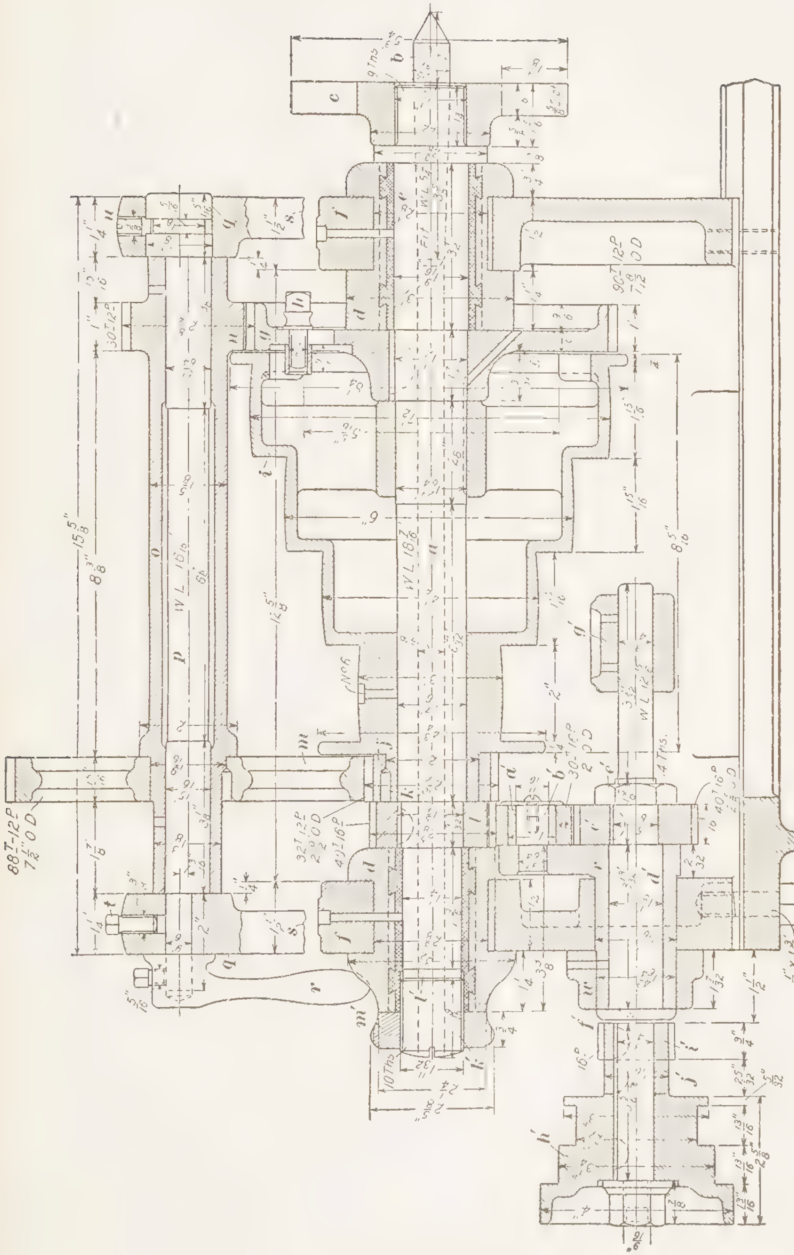


Fig. 20

the two. The adjusting screws *r* furnish a means of changing the position of the dead center sidewise on its base *s*. The base has grooves that fit the ways on the bed, and on its upper side it has two lugs *t* against which the screws *r* bear. The screws *r* are made with 8 left-hand threads per inch. The abbreviation *W. L.* is used frequently on the drawing to indicate the whole length, or over-all length, of a part.

45. Lathe Headstock.—A longitudinal section of a headstock for a lathe is shown in Fig. 20, and in Fig. 21 is an

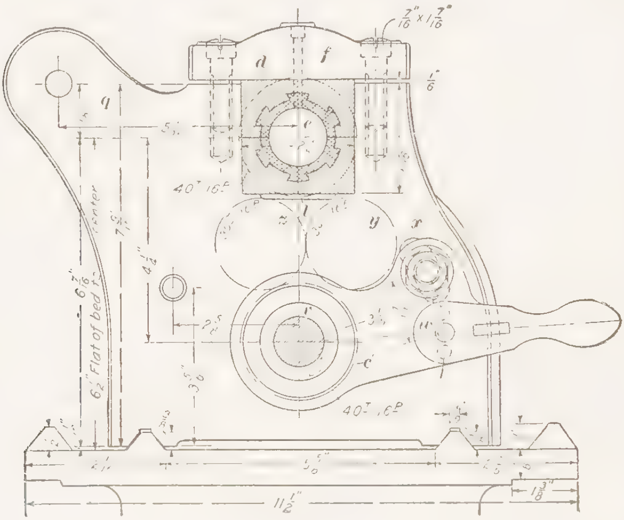


FIG. 21

end view showing the center lines of several parts, but omitting details. The spindle *a* is of different outside diameters at various points and is drilled with a $\frac{9}{16}$-inch hole except at the inner end, where the hole is tapered to receive the live center *b*. The large end is made $1\frac{1}{2}$ inches in diameter and a screw of 9 threads per inch is cut on it, so that the face plate *c* may be screwed on. The face plate is screwed up until it comes firmly against the collar, which is $\frac{3}{8}$ inch wide. The threaded hole in the face plate is beveled at the ends, to allow the face plate to come solidly against the collar and to give a good start to the threading tool. Slots $\frac{5}{8}$ inch wide and $1\frac{3}{8}$ inches

deep are cut on opposite sides of the center of the plate, to receive the tail of the dog that holds the work. The spindle turns in cast-iron bearing boxes *d* lined with Babbitt metal *e* that is held in by means of dovetailed slots. The boxes are split in halves, as is indicated by the fact that the section lining, or cross-hatching, runs in opposite directions in the upper and lower parts of the boxes. These boxes are fitted into square slots in the frame of the headstock and are held in place by the caps *f*. Oil holes are drilled through the centers of the caps and the upper half of each box to enable oil to be supplied to each bearing.

46. To the spindle *a*, Fig. 20, is keyed the gear *g*, which has 90 teeth of 12 pitch and an outside diameter of $7\frac{8}{12}$ inches, as indicated by the abbreviation *O. D.* This gear has a short slot near the outer rim, in which is a screw *h* that may be moved so as to lock the gear to the cone pulley *i*. The cone pulley is loose on the spindle, and at its smaller end there is fastened to it a small gear *j* by a pin key *k*. This small gear, or pinion, as it is called, has 32 teeth of 12 pitch, and an outside diameter of $2\frac{10}{12}$ inches. Beside it, also keyed to the spindle, is another pinion *l*, made of steel, as shown by the cross-hatching, and having 40 teeth of 16 pitch. When the work is to be rotated rapidly, the screw *h* is set so as to lock the cone pulley and the gear *g*, and the driving belt is put on one of the steps of the cone pulley. The spindle is thus caused to turn at the same rate as the cone pulley and the gear *g*, thus rotating the work by means of the face plate *c*.

47. When the work in the lathe is to be turned slowly, the back gearing is brought into action. It consists of a pair of gears *m* and *n*, Fig. 20, on a sleeve *o* that is loose on a shaft *p* held in brackets *q*. The gear *m* is held to the sleeve by a pin key, but the pinion *n* is in one piece with the sleeve. The shaft *p* is eccentric; that is, its center line does not pass through the centers of the holes in the brackets *q*. As a result, when the handle *r* fixed on the smaller end of the shaft *p* is pushed over away from the spindle, the gears *m* and *n* are swung backwards, and are drawn out of gear with the wheels *j* and *g*.

When the handle is drawn forwards, the gears m and n are caused to engage with the gears j and g. When the back gears are thrown into action, the screw h is set so that the cone is free from the gear g. The cone then turns freely on the spindle, rotating the pinion j, which turns the gear m on the sleeve o. As the pinion n must turn with the sleeve o, motion is given by it to the gear g, which is fast to the spindle, and thus the spindle and the work are rotated; but the speed is much slower than when the cone pulley drives the gear g directly.

48. The back gearing in Fig. 20 is shown directly above the spindle a, but this is not its actual position. As may be seen in Fig. 21, the brackets q supporting the shaft p are behind the spindle instead of directly above it. In Fig. 20, therefore, the brackets q are not shown joined to the frame of the headstock, but are left with broken lines at s, indicating that a conventional section is shown, rather than a true section. The setscrew t is screwed down when the shaft p is to be held firmly, so as to keep the back gears in action or out of action. A disk of copper or brass between the setscrew and the shaft prevents the latter from being injured. The setscrew u is flattened, and its end fits a groove turned in the enlarged end of the shaft p. In this way the shaft cannot move endwise, but may turn in its supports q. Oil holes are drilled through the sleeve o to admit oil to those parts of the shaft p on which the sleeve turns.

49. Passing through a bored hole in the outer part of the headstock frame is a bronze sleeve v, Figs. 20 and 21, to which is pinned a lever w that may be used to turn the sleeve through a small angle, and that may be locked in position by tightening the nut of the clamp bolt in the slot x. At the inner end of the sleeve is formed an arm carrying two steel pinions y and z having 30 teeth each. These two pinions mesh with each other, and either one may be swung into mesh with the gear l on the spindle a by moving the handle w. Each of the pinions y and z turns on a bronze bushing a' fitted on a pin b' that is riveted to the arm of the sleeve v. A washer held in place by a screw prevents the pinion from running off. The pinion z

gears with a small 40-tooth wheel c' that is keyed to the shaft d' and is held in place by the nut e'. This nut, in connection with the collar f', keeps the shaft d' from moving endwise. The shaft rotates in the bronze sleeve v and the cast-iron bearing g' fixed to the headstock casting. At the outer end of the shaft are keyed the cone pulley h' and the pinion i', separated by a short sleeve j' that is also keyed to the shaft.

50. A plug k', Fig. 20, is threaded over its entire length and is screwed into the end of the box forming the outer bearing of the spindle a. A fiber washer or ring l' is placed between the plug and the spindle, and the plug is then screwed up against the washer. In this way the fiber washer and the plug take the end thrust of the spindle. The nut m' acts as a lock-nut to keep the plug from turning when it has been correctly set.

The section shown is a conventional one in several respects. The matter of showing the back gearing above the spindle has already been mentioned. The pinion z is shown between the pinions l and c' as if it were on a vertical line between their centers, whereas, Fig. 21 shows that the pinion z is not on the vertical center line. The keys shown in the sectional view, Fig. 20, are semicircular in shape and are known as Woodruff keys. In the end view, Fig. 21, none of the gear-wheels are shown in full, but they are indicated by circles on which the number of teeth and the pitch are written.

BLUEPRINTING

51. Blueprinting is a process of duplicating drawings that have been made on tracing paper or cloth.

All blueprinting processes are based on the action of light on certain chemicals with which the blueprint paper is coated; therefore, in the process of manufacture the coating is done in a dark room, and the paper must be kept away from light until used.

To make a blueprint on the sensitized paper, a frame similar to that shown in Fig. 22 is used. This frame holds a large

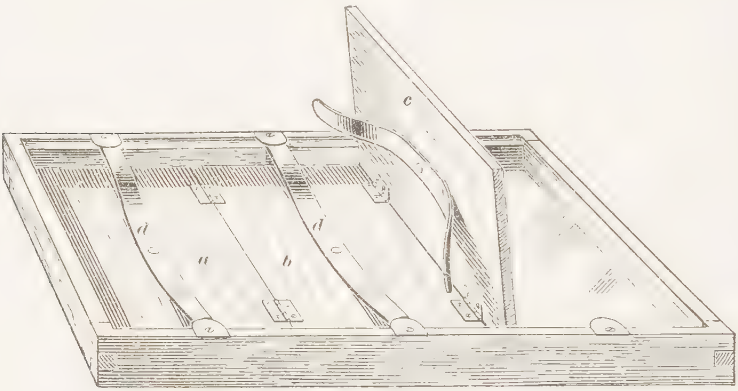


FIG. 22

plate of glass, and the removable back of the frame is made in three sections *a*, *b*, and *c*, which are hinged together and are held in place by spring clips *d*. The inked surface of the tracing cloth is laid in contact with the glass, and the sensitized paper is placed with the coated side next to the tracing cloth. A piece of felt or blotting paper is then placed at the back and the frame is closed ready for making the print. All this preparation should be done in a subdued light.

The frame is then placed so that the sunlight strikes the glass squarely, the angle of the frame being changed when necessary

to suit the position of the sun. The light shining through the glass and the tracing acts on the coating of the paper at all parts not protected by the black lines of the tracing, but under the lines no action takes place. After exposure to the light for the proper length of time the paper is removed and washed in water for about 5 minutes. The part of the paper that has been acted on by the light will turn blue and the parts not acted on will remain white; the result is a print having white lines on a blue ground.

52. Exposure.—An exposure of 1 minute is considered correct for paper of the quick-printing variety when printed at about midday on a clear day in midsummer, at which time the action of the sunlight is strongest. The time of exposure, however, will vary with the month of the year, the time of day, and the intensity of the light. Some papers also are more sensitive than others. Therefore, to obtain prints with clear lines and good blue color, some judgment will have to be used in determining the proper length of exposure under varying conditions.

The length of exposure necessary to obtain the color of print desired may be determined by making a test, as follows:

Take a strip of blueprint paper about 12 inches long and 2 inches wide. In subdued light, mark off equal divisions on it with a lead pencil and number the parts *1*, *2*, *3*, *4*, *5*, *6*. Expose the whole strip for 10 seconds, then cover the part of the strip marked *1* with a piece of cardboard or anything that will prevent the light from striking the part covered. After 10 seconds more, extend the cover over part *2*, and at the end of a third interval of 10 seconds cover also part *3*, etc. When the minute is up, part *1* will have been exposed 10 seconds, part *2*, 20 seconds, part *3*, 30 seconds, etc., part *6* having been exposed 1 minute. Then remove the paper and wash as described, and when it is dry select the specimen having a good deep shade of blue. The number on the part chosen will indicate the length of time that the print was exposed. Of course, such a test could be made to extend to any desired length of exposure.

53. Treatment of Old Blueprint Paper.—Formulas for coating blueprint paper can be found in almost any library, but it is cheaper and better to purchase paper already prepared. Ordinary commercial blueprint paper for sunlight exposure will keep from 4 to 6 weeks before commencing to deteriorate. If the paper is old or the print slightly overexposed, the lines will appear pale blue and the background fairly dark after washing. Such a print may be improved by treatment with a solution of potassium bichromate.

The bichromate is dissolved in water and the solution is diluted until of a light amber color. The print, that has been made and washed in the usual manner, is immersed in this solution, then taken out, rinsed in water, and dried. This treatment clears the background and bleaches the lines white, thus improving the contrast.

In this way it is often possible to make a fairly good print on paper that otherwise, on account of its age, would not give satisfactory results.

54. Making Alterations on Blueprints.—If alterations are desired on a blueprint, white lines can be drawn on the print by use of an ink consisting of a strong solution of carbonate of soda, which is common washing soda.

55. Prints With Blue or Brown Lines.—It is sometimes desirable to have a blueprint showing blue lines on a white ground—similar to a tracing. This is obtained by first making a master print on sepia paper, which gives white lines on a brown background, and using this print as a negative from which to make a print. The sepia paper has a coating of a silver salt that is acted on by sunlight in the same manner as is the blueprint paper. A blueprint does not make a satisfactory negative, because the blue background does not offer sufficient resistance to the action of light.

In making the brown print that is to be used as a negative, the tracing must be put into the frame so that the inked surface is in direct contact with the sensitized surface of the sepia paper. Note that this is contrary to the practice in making ordinary blueprints, in which the inked side of the

tracing is next to the glass. This difference is necessary, as otherwise, in the print made from the negative, right and left would be reversed.

After an exposure of from 2 to 3 minutes in the sun, the paper will show the image faintly and the edges beyond the tracing will be of a deep tan color. The print is then taken

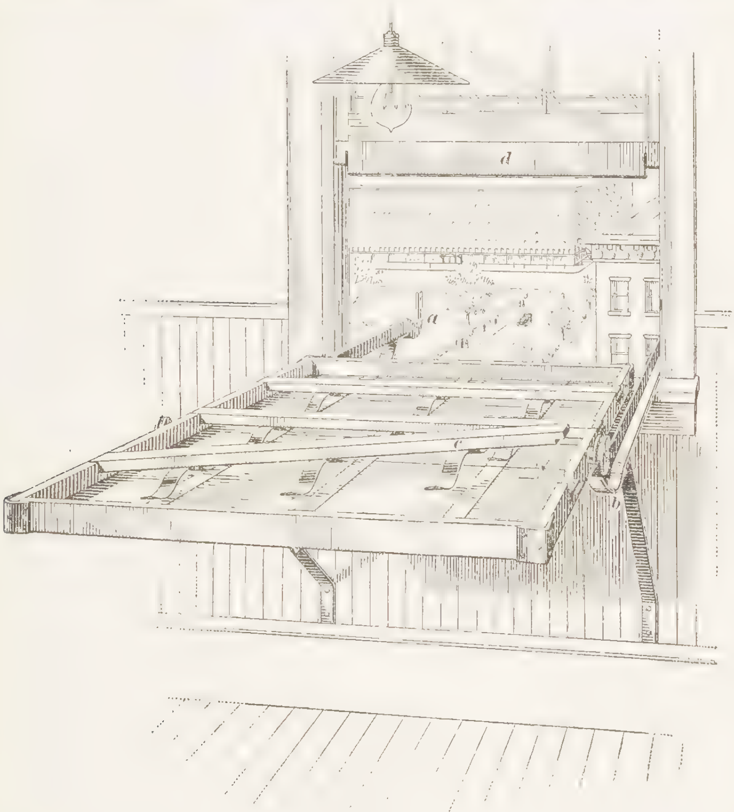


Fig. 23

out and washed for about 5 minutes in clear water and placed in a fixing bath made of about 1 ounce of hyposulphite of soda to 1 gallon of water. The print is left in this bath for about half a minute, then washed in running water for about 10 minutes and hung up to dry.

To make a print with blue lines on a white ground, this negative is placed in the printing frame so that the surface showing the image is in contact with the sensitized surface of the blueprint paper and is exposed to the light in the same manner as in making other blueprints, though the length of exposure will have to be determined by trial. The resulting print will show blue lines on a white ground.

A print having brown lines may be produced in like manner by exposing sepia paper under the negative print. The time of exposure will be 10 or 15 minutes and the print should be washed and fixed as already described.

56. Blueprinting Apparatus.—For making large blueprints, an apparatus similar to that shown in Fig. 23 is convenient. This consists of a large printing frame resting on tracks that extend outside of a window and have curved ends *a* and *b*. The frame is pivoted on rollers attached to its sides and so placed that they are slightly forward of the center of the frame when the glass side is uppermost; the track is made just long enough so that when the rollers rest in the curve *a* the rear end of the frame rests on the window sill.

The tracing and paper are put in the frame while it is in the position shown in Fig. 23. After the back and the clamps *c* are in place, the frame, which rests on the rollers in the curved ends *b* of the track, is revolved to bring the glass side uppermost and is pushed out till the rollers rest in the curved ends *a*. After exposure, the frame is drawn in, revolved, and the print taken out.

The window shade should be pulled down while putting in and taking out the paper, to avoid the action of the strong light, which might spoil the paper.

A piece of wood fastened to the sash, as at *d*, will make it possible to close the window over the rails.

There are various methods of constructing such tracks and supports for the printing frame, and either wood or iron may be used, but all operate on the same principle.

57. For printing by electric light with the same frame as shown in Fig. 23, the frame is turned glass side up but kept

inside the room, the inner end being supported by a trestle or other suitable means. A high-candlepower incandescent lamp is arranged to swing above the frame and a hood or reflector concentrates the light on the glass. The lamp is usually kept in motion during the exposure, which will be longer than required for bright sunlight.

There are on the market various kinds of blueprinting machines for use where large numbers of blueprints are required, but for ordinary requirements the apparatus described will be sufficient.

58. Apparatus for Washing Prints.—For washing blueprints it is convenient to have a tray large enough to allow the print to be laid out flat and to have running water. Such a tray may consist of a suitable-sized wooden box 4 to 8 inches deep and lined with zinc or galvanized iron. This tray may be set under a water faucet, and it should have a drain hole with plug at one corner so that the water may be drawn off.

Should it be necessary to wash a print larger than the tray, the print may be lightly folded with the coated side out and kept moving when immersed in the water. Use plenty of water.

SHIP DRAFTING
(PART 1)

INTRODUCTORY EXPLANATIONS

DEFINITIONS

1. From a shipbuilder's standpoint, a **ship** is any structure of steel or wood that will float in water and carry a load. The term **vessel** also is used with a similar meaning.

As a rule, the terms vessel, boat, and ship are used indiscriminately by the public, and for this reason each will be briefly defined.

Boat, in a broad sense, means any water craft; generally, it indicates a small open vessel or water craft moved by oars or paddles, but often by a sail or some power mechanism. Usually, the term boat is used in combination with some word descriptive of the use or mode of propulsion, such as rowboat, sailboat, motor boat, pilot boat, fishing boat, and so on.

By a *vessel* is meant a craft designed to float on the water, usually one larger than an ordinary rowboat, in fact any water craft *constructed with a deck*. This term may therefore be applied to any craft afloat larger than a rowboat. According to definition given by the Revised Statutes of the United States, the term vessel indicates every description of water craft or other artificial contrivance used, or capable of being used, as a means of transportation on the water.

The term **ship,** on the other hand, properly means a large seagoing vessel, usually with three or more masts carrying sails. In general, it means a vessel of considerable size, and

suitable for deep-water navigation. A ship whose motive power is steam is termed a **steamship** and sometimes **steamer.**

A ship or any large vessel is not properly designated a boat, which term should be used only when referring to open craft of small size, except when a special modifying word precedes the term, as in power boat, torpedo boat, towboat, etc.

Vessels used for purposes of transportation, but provided with no means of propulsion, are called **scows** or **barges;** these are usually moved by towing. Barges are of two kinds, those that carry a load entirely on deck, as for instance a car float, which is provided with tracks on the deck; and barges that carry the load below deck, as a coal barge. The harbor lighter, which usually is provided with a steam hoisting engine and a derrick, is of the first-mentioned class. Scows and deck-load barges usually have square or sloping ends, straight sides, and flat bottoms. Some coal barges are scow-shaped and others are ship-shaped; that is, have curved lines like a ship.

Self-propelled vessels were originally moved by means of sails, and then, of course, their speed depended on the wind as well as on their shape. In 1807, Robert Fulton applied the steam engine to ship propulsion, and since then the use of steam has constantly increased. Steam was generated originally in coal-burning boilers, but now oil is extensively used for fuel; in fact, all new United States Navy vessels burn oil. A more recent motive power is the internal-combustion engine, which consumes heavy oil in the cylinders, thus eliminating the boilers entirely.

Ships originally were built of wood, but at present steel is the chief material of construction, as it makes a lighter and stronger vessel and gives more internal volume for the same outer size.

2. Displacement.—The extent of a structure's ability to float and to carry a load is determined from the principle of Archimedes that *a floating body displaces its own weight of water; or, inversely, the weight of water displaced or set aside by a floating body equals the weight of the body.* Hence, a ship's **displacement** is the weight of the ship and the load

that she carries. The **dead weight** is the weight of cargo, fuel, reserve feedwater for boilers, drinking water, stores, passengers, and crew, and is always the difference between the displacement and the weight of the ship complete, which of course includes the weight of the propelling machinery. Thus, if a ship has a displacement of 8,000 tons and the weight of hull and machinery is 3,500 tons, she is carrying a dead weight of 8,000−3,500=4,500 tons. The **ton** in ship work is always understood to be the long ton of 2,240 pounds, except on the American Great Lakes, where the ton of 2,000 pounds frequently is used. This ton *weight* must not be confused with the ton *measure* of 100 cubic feet, which is used in tonnage calculations, as explained more fully later on under the head of *tonnage*.

3. Shipbuilders' Terms.—Among shipbuilders and nautical men many terms are used that are peculiar to the business.

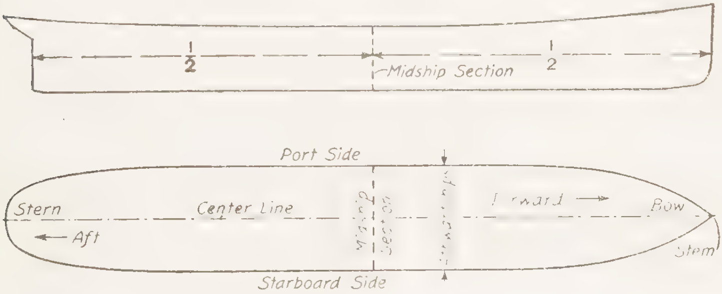


FIG. 1

ness. A number of those commonly used are here defined and some of those of general application are illustrated in Fig. 1. The meaning of many of the others and of those that may be encountered from time to time in the text will best be understood by referring to the lettered parts on the various illustrations and plates.

4. The **hull** is the body of a ship, exclusive of masts, rigging, and machinery. A **deck** is a platform, or horizontal structure, covering or dividing the space within a ship's hull and forming the top of a compartment. A **hatch** is an opening

in a deck affording passage to a hold for cargo; the raised structure surrounding a hatch is called a **hatch coaming.** The **hold** is the space below decks that is used for the stowage of cargo, etc.

The *fore,* or front, end of a boat or ship is called the **bow;** the *after,* or rear, part is the **stern.** The foremost part of the ship's structure, the part that cleaves the water, is called the **stem.**

The direction toward the bow is called **forward;** toward the stern is **aft.** In speaking of the position of any part relatively to another part, the terms **before** or **abaft** are used in the sense of *forward of* or *aft of,* respectively.

The **center line** extends through the center of the ship from bow to stern. This line divides the ship into two equal parts and coincides with the direction of the **keel,** which is the lowest lengthwise member of the ship's structure. The part of a ship on the right of a person on the ship and facing the bow is known as the **starboard** side, and that on the left, as the **port** side.

The **midship section,** a term more accurately described later, is a vertical cross-section of a ship taken midway between the bow and the stern, this part being usually the widest and fullest.

The distance from the bottom of the keel to the surface of the water when the ship is afloat is the **draft** of the ship, or the **amount of water the ship draws.** The **load draft** is the draft to which it is permissible to load a vessel. The difference between the drafts forward and aft is called the **trim,** and the mean between the two drafts is called the **mean draft.** For example, a ship drawing 22 feet of water forward and 24 feet aft is said to **be trimming, or to trim,** 2 feet by the stern, and her mean draft is $\frac{22+24}{2}=23$ feet. The mean draft is used in calculating the displacement of a ship.

The **freeboard** is that part of a ship's side between the surface of the water and the upper side of the uppermost complete deck, a **complete deck** being one that extends the full length and width of the ship.

Ship-shaped bodies are tapered, or **fined**, to use a marine term, toward the ends. If the middle portion of the vessel is of constant form for any considerable distance, the vessel is said to have a **dead-flat, or parallel, middle body** of that length. The fining of the ends permits the vessel to pass through the water with less disturbance and hence by the expenditure of a smaller amount of power than if she were square ended.

5. Coefficients.—For the purpose of comparison of the models, or forms, of ships having different proportions, various coefficients are used. The more commonly used of these are here explained and illustrated with reference to a ship 400 feet long, 50 feet wide, drawing 25 feet of water, and displacing 10,000 tons of salt water at that draft.

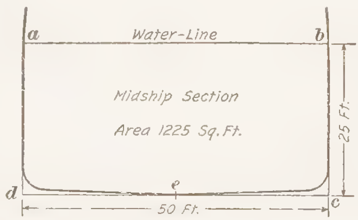


FIG. 2

6. The **block coefficient** is used to express the *fineness* of a vessel's model. The block coefficient is the ratio between the volume of the submerged portion of the vessel and the volume of a rectangular block of the same length, breadth, and draft as the ship. As in this case the ship displaces 10,000 tons of salt water, and 35 cubic feet of water weighs 1 ton, the volume of the ship below the water-line is $10{,}000 \times 35 = 350{,}000$ cubic feet. The volume of the surrounding rectangular block of the same depth is $400 \times 50 \times 25 = 500{,}000$ cubic feet. Then the block coefficient is $\frac{350{,}000}{500{,}000} = .70$. The greater the block coefficient, the fuller is the vessel and the nearer does its volume approach that of the surrounding block. The block coefficient of cargo steamers varies from about .70 to .82, while for yachts, torpedo boats, and other fast craft it runs as low as .35 or .40.

7. The **midship-section coefficient** is the ratio between the area of the immersed portion of the midship section of a vessel and the area of the circumscribed rectangle. In Fig. 2,

a c b represents the immersed portion of the midship section and its area is given as 1,225 square feet. According to the dimensions given, the area of the circumscribed rectangle *a b c d* is $50 \times 25 = 1{,}250$ square feet; the midship-section coefficient is therefore $\frac{1{,}225}{1{,}250} = .98$.

8. The **prismatic coefficient** is the ratio between the volume of that part of a ship below water-line and the volume of a prism having a length equal to that of the vessel and a cross-section equal to the submerged part of the midship section. In this case, as shown in Fig. 2, the area of the submerged part of the midship section is 1,225 square feet, and as the length of the ship is 400 feet, the volume of the prism is

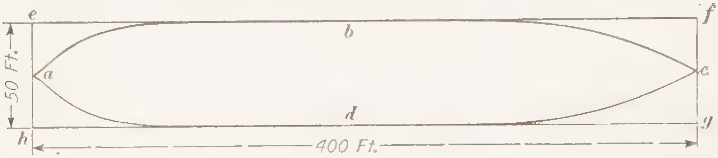


FIG. 3

$400 \times 1{,}225 = 490{,}000$ cubic feet. As already found, the volume of the submerged portion of the ship is 350,000 cubic feet; then, the prismatic coefficient is $\frac{350{,}000}{490{,}000} = .795$.

9. The **water-line coefficient** is the ratio between the area included by the water-line of a ship and the area of a circumscribed rectangle. For example, in Fig. 3, *a b c d* is the plan of the ship's water-line, and the area included by it is given as 15,200 square feet. The area of the circumscribed rectangle is $400 \times 50 = 20{,}000$ square feet. The water-line coefficient therefore is $\frac{15{,}200}{20{,}000} = .76$.

Naturally, all these coefficients change with change of draft.

TYPES OF SHIPS

10. Throughout the discussion of vessels, it is necessary to refer to different types of ships or vessels and their structural parts. Frequent mention must also be made of the many spaces into which vessels are divided. In doing this, technical terms must be used which, though familiar to shipbuilders and seafaring men, are not a part of the vocabulary of those not connected with ships and shipping, therefore it is advisable first to distinguish and illustrate the main types of ocean vessels and to designate the locations and names of the main structural parts and the principal spaces within such vessels.

11. Structural Designation of Ships.—A vessel's type is indicated by the number of its decks, by the characteristics of its structures above the main deck, by the fuel it uses, and by the kind of engines and the number of propellers with which it is equipped. There are many variations in the structural details of vessels, but the main types of ships may be designated as just mentioned.

12. Names of Decks.—Small freight vessels have one deck; medium-sized freight and passenger ships have one or two decks; large freight vessels and those carrying both freight and passengers usually have three or more full decks, above which there may be one or more decks extending less than the full length of the vessel and enclosing successive tiers of superstructures. When there are three decks they are designated as the *lower,* the *main* (or *middle*), and the *upper deck.* If there are four full decks, the fourth deck is generally called the *shelter deck,* above which there may be a *bridge deck,* a *promenade deck,* and a *boat deck.* The decks above the shelter deck do not extend the full length of the hull.

The nomenclature of decks varies with different owners and builders and is not necessarily constant. A system largely in vogue at the present time designates the upper continous deck as the *upper* or the *shelter* deck, depending on its strength, and those below as *second* deck, *third* deck, etc.

A lower deck not extending the full length of the vessel is sometimes called the **orlop** deck.

Figs. 4 and 5 are half midship sections showing the names and locations of the different decks and some of the features

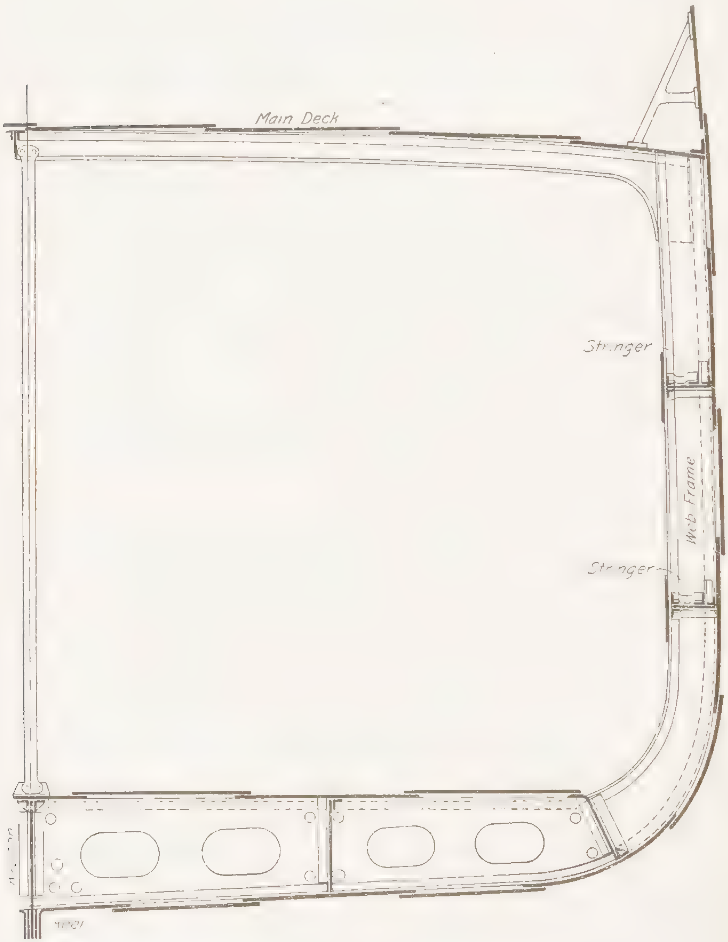


Fig. 4

of construction. Fig. 4 represents a single-deck vessel, and Fig. 5 a two-deck vessel; the locations of other decks are shown further on, in Figs. 11 and 12.

13. Single-deck vessels are used principally for carrying coal, lumber, and other kinds of cargo that is not damaged by high (that is, deep) stowage, but large single-deck vessels are not well suited for package freight, the bottom cases of

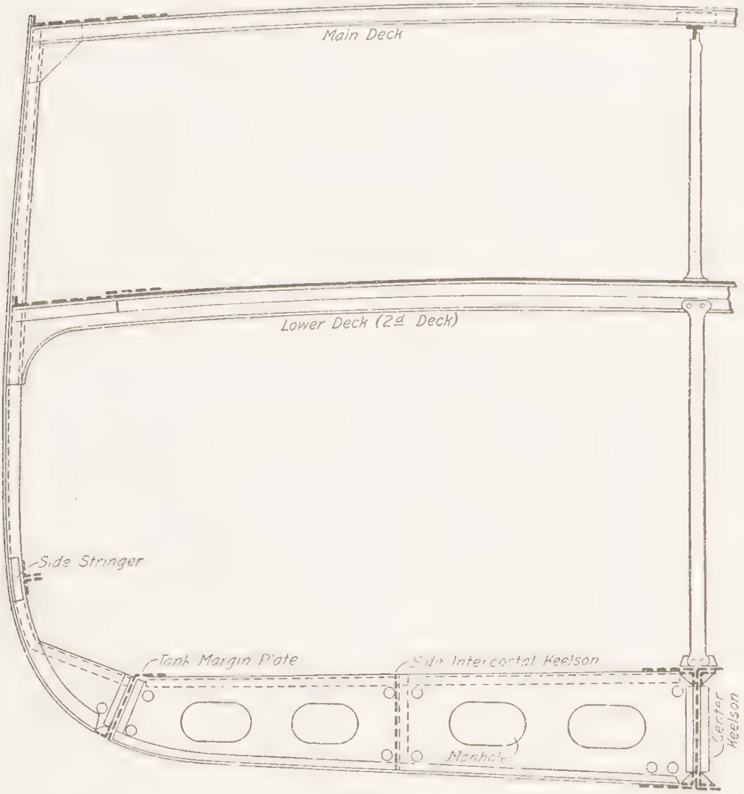


FIG. 5

which would be damaged if stowed deep. Besides, in a single-deck vessel the cargo on top must always be unloaded first; whereas, in a ship having several decks, cargo may be discharged from all the decks at once through the hatches or through ports in the sides of the shell, these ports of course being water-tight when closed. Such cargo-handling facilities are of advantage to a vessel calling at several different ports

14. Ship-Construction Methods.—To make plain some of the methods used in constructing vessels, Fig. 6 is given. This shows partly in perspective a half midship section

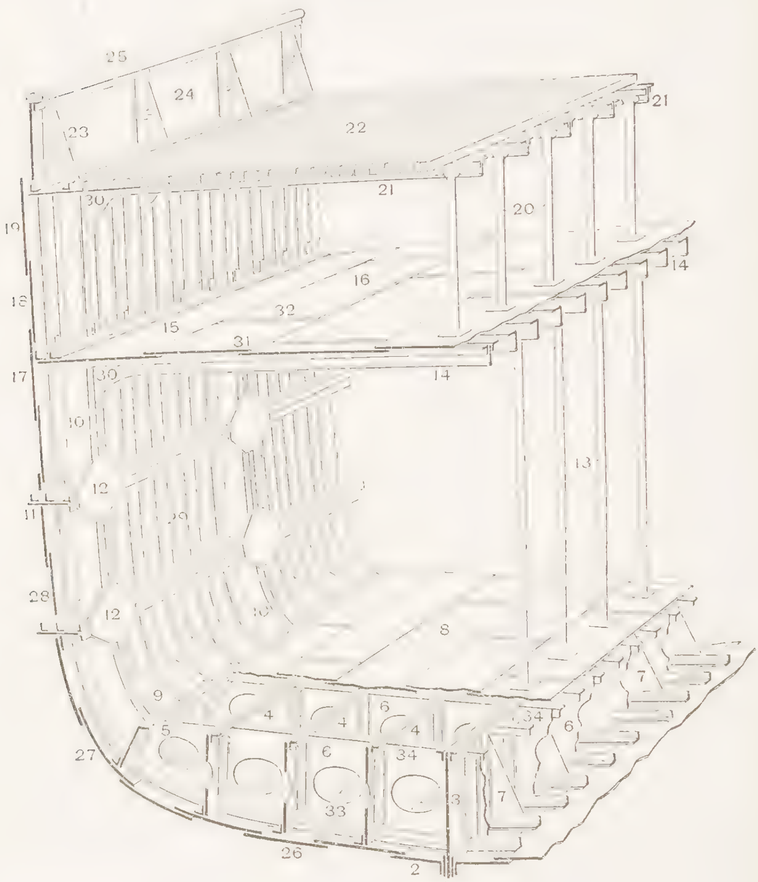


FIG. 6

of a two-deck vessel having web frames and a double bottom. The names and locations of the various members can be found from the numbers on the cut and the references on the opposite page. From this illustration and the list it will be possible to identify the principal parts that may be mentioned in the following pages.

Names of Parts Indicated by Numbers

1 Keel; side bar keel.
2 Garboard; garboard strake.
3 Center girder; vertical center plate; center through plate keel or keelson.
4 Side girders; side keelsons.
5 Margin plate.
6 Floors; intercostal floors.
7 Brackets.
8 Inner bottom; top of double bottom; top of tank.
9 Bilge brackets.
10 Web frames.
11 Side stringers.
12 Diamond plates.
13 Hold pillars; hold stanchions.
14 Main-deck beams.
15 Main-deck stringer.
16 Main-deck plating.
17 Main-deck sheerstrake.
18 Topside strake.
19 Upper-deck sheerstrake.
20 Upper-deck pillars; upper-deck stanchions.
21 Upper-deck beams.
22 Upper deck.
23 Bulwark stay.
24 Bulwark plating.
25 Main rail.
26 Bottom shell plating.
27 Bilge shell plating.
28 Side shell plating.
29 Ordinary frames out of inner bottom.
30 Deck beam brackets.
31 Edge laps of shell and deck plating.
32 Butt laps of tank top and deck plating.
33 Frames in inner bottom.
34 Reverse frames in inner bottom.

The strength of a vessel depends upon the weight and strength of its transverse framing, which consists of the floors *6* and frames *33*, *34*, and *29* to which the plates enclosing the hull are riveted. The minimum size of frames for different types of vessels is prescribed by the rules established by Lloyd's Association and similar organizations which classify vessels and give them the rating upon which insurance rates depend. The transverse frames are placed from 18 to 36 inches apart and the framing may be strengthened in various ways: (1) By *deep framing,* that is, by making the transverse frames deeper and stronger; (2) by substituting web frames or beams for each sixth to tenth transverse frame; and (3) by increasing the number and dimensions of the longitudinal beams or stringers that give longitudinal strength to the vessel.

The longitudinal strength depends on the strength of the top and bottom members of the ship's structure. A ship may be considered a beam, and when floating with the crest of a wave amidships, it is largely supported amidships and has little support at the ends. Thus the ends tend to sag and the top deck is put in tension and the bottom in compression. This is called a *hogging* condition. If the ship is floating with the hollow of the wave amidships the reverse is the case; that is, the support is largely at the ends and the middle tends to sag and

put the bottom in tension and the top deck in compression. This is called the *sagging* condition. It is, therefore, readily seen that the top deck and the ship's bottom plating and the inner-bottom plating are very important strength members, and the heavier these are the greater stress they can stand. Accordingly, for the same size, that vessel which has these members the heavier can safely load to a deeper draft.

15. Practically every vessel is now constructed with a double bottom, the space between the inner and outer plating being used to carry water ballast. Certain compartments may be used to carry fresh water for the boilers, and in the case of ships with oil-burning boilers or internal combustion engines a portion of the tank space in the double bottom may be used to store fuel oil.

The prevailing method of constructing the double bottom of vessels is illustrated in Fig. 6. The form shown is called a

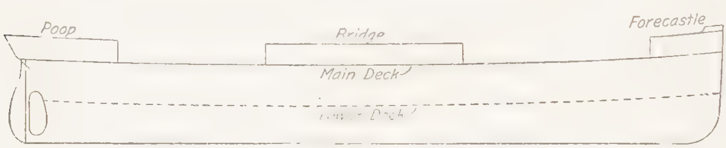
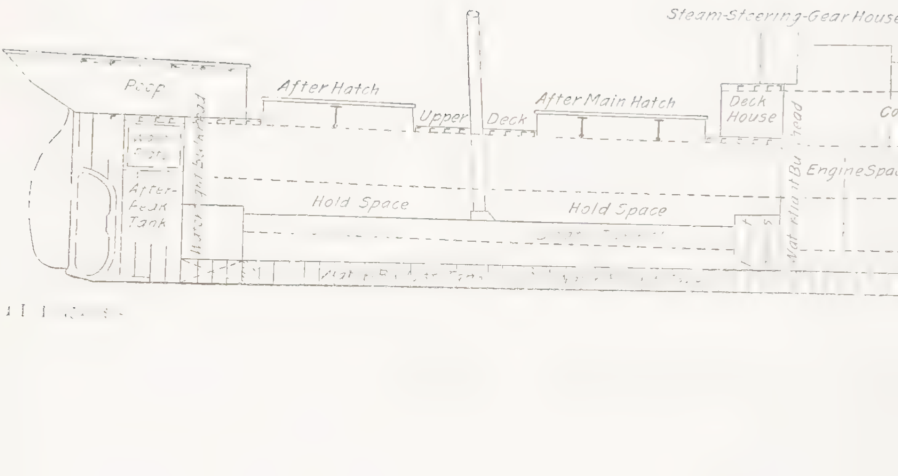
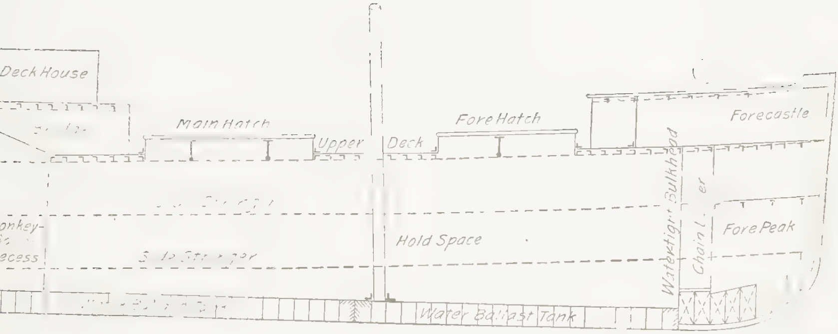


Fig. 7

cellular double bottom. The floors are vertical plates supporting the inner bottom, and are not horizontal plates as the name would indicate. As shown in Fig. 6, the side girders, or side keelsons, *4* extend parallel to the center keelson *3*, and are intercostal between floors *6*. By the term **intercostal,** it is meant that the member is cut at the parts between which it is said to be intercostal. The floors *6* are continuous between the center keelson and the margin plate *5*.

16. The framing of the vessel shown in Fig. 6 consists of ordinary frames *29* with web frames *10* every fifth frame and heavy longitudinal side stringers placed intercostally between the web frames, the stringers being cut at each web. The web frames extend only to the main deck and there is a main-deck beam *14* connected by a bracket *30* to each frame; the main-deck floor is of steel plates *16*. The upper-deck construction


Steam-Steering-Gear House
Poop
After Hatch
Upper
Deck
After Main Hatch
Deck
House
Hold Space
Hold Space



Deck House
Main Hatch
Fore Hatch
Upper
Deck
Forecastle
Watertight Bulkhead
Fore Peak
Hold Space
Water Ballast Tank

is lighter; there are beams only for each alternate frame and the deck flooring is of wood. Instead of using web frames to strengthen the hulls of vessels from which, as in Fig. 10, the lower deck is omitted, it is now more usual to employ deep framing; that is, to use for the frames deeper angles all of the same size. This method gives better cargo stowage.

17. The present-day practice is to omit also the side stringers, except in the ends of the vessel, as they break up cargo stowage and make the structure more complicated. Their original purpose was to serve as beams to support the frames, and the stringers were in turn supported by transverse bulkheads at distances of 50 feet or more apart. Without stringers, the frames are supported at the margin plate and at the deck, and as the distance between these two points of support is less than the usual length between the bulkheads in the hold, the strength is obtained in the least dimension. By making the ordinary transverse frame heavier and stronger, the transverse strength is maintained at a much lower cost in material and in a simpler manner. Stringers tie the frames together and prevent them from lying down, or buckling, but it is doubtful whether the tendency for the frames to lie down is so great as has been supposed.

18. Well-Deck Steamers.—The early ocean steamers were and many freight vessels now in service are constructed with two full decks, a lower and a main deck, above which are placed the three usual superstructures—the forecastle, the bridge, and the poop. The outline sketch, Fig. 7, indicates the general design of the two-deck vessel. The spaces between the forecastle and the bridge and the bridge and the poop are sometimes called **wells**, and such a steamer is called a **well-deck steamer.**

19. In Fig. 8, which is a detailed profile of a simple, single-deck, well-deck steamer, can be seen the location of the main parts of the ship. The vessel has a double bottom containing water-ballast tanks. As is customary, the narrow parts of the ship at the bow and stern contain peak tanks that are generally

used to carry water ballast. The bridge, as is usual, is built around the casings that enclose the smokestack and the ventilating spaces above the engine and boilers. The poop and the forecastle are closed in and used for crew's quarters and freight stowage. The profile also shows such other parts of steamers as the anchor-chain locker, bulkheads, hatches, shaft tunnel, engine space, boiler space, donkey boiler recess, water-ballast tanks, steering-gear house, deck houses, etc. A study of the names and locations of the parts shown will render understandable any references to them that may be made in succeeding pages.

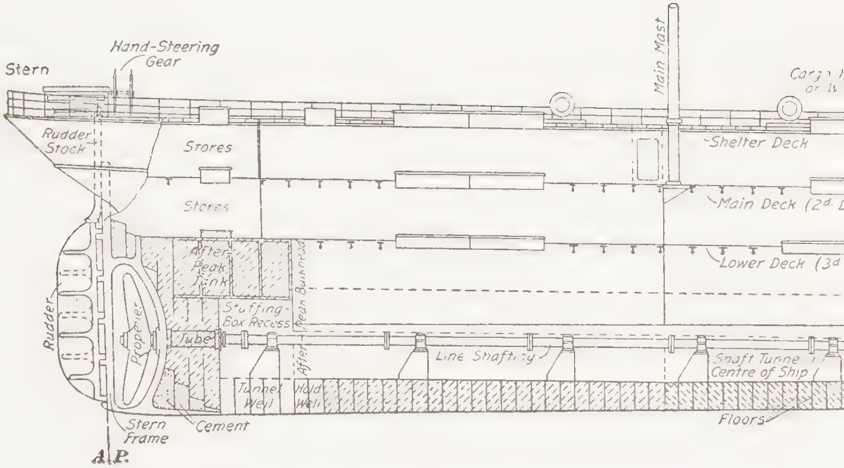
20. Ships Classed According to Framing and Decks.—According to the strength of the structure, a vessel is called either a *full-scantling* ship; a *spar-deck* ship; an *awning-deck* ship, or a *shelter-deck* ship.

In a **full-scantling**, or *three-deck,* ship the frames are carried full size to the upper continuous deck, called the *upper deck,* which in this case is the strength deck of the ship, and the deck below it may be called the *second deck.*

When the frames between the second deck and the upper deck are made somewhat lighter than those below and the upper deck also is of lighter construction, the vessel is a **spar-deck** ship; and if the construction above the second deck is still lighter and the second deck is the strength deck, the vessel is called an **awning-deck** ship. The space between the awning deck and the second deck is closed against the entrance of the sea and is used to carry passengers, cattle, or light cargo.

If there are one or more permanent openings or hatches left in the upper continuous deck, so that in heavy weather the sea might invade the space between the upper and the second decks, the upper continuous deck is called a **shelter deck**—not an awning deck—and the vessel is called a **shelter-deck** ship. Fig. 9 is a profile of a shelter-deck cargo steamer.

Fig. 10 is a midship half section showing one form of construction of a vessel with two decks besides a shelter deck. In this case the framing is reduced in strength above the third deck and is still lighter above the second deck.



Hand-Steering
Gear
Stern
Main Mast
Rudder
Stock
Stores
Stores
Shelter Deck
Main Deck (2d
Lower Deck (3d
After-
Peak
Tank
Stuffing-
Box Recess
After Peak Bulkhead
Rudder
Propeller
Tube
Line Shafting
Shaft Tunne
Centre of Ship
Tunnel
Well
After
Hold
Well
Stern
Frame
Cement
Floors
A.P.

I L T 154 815

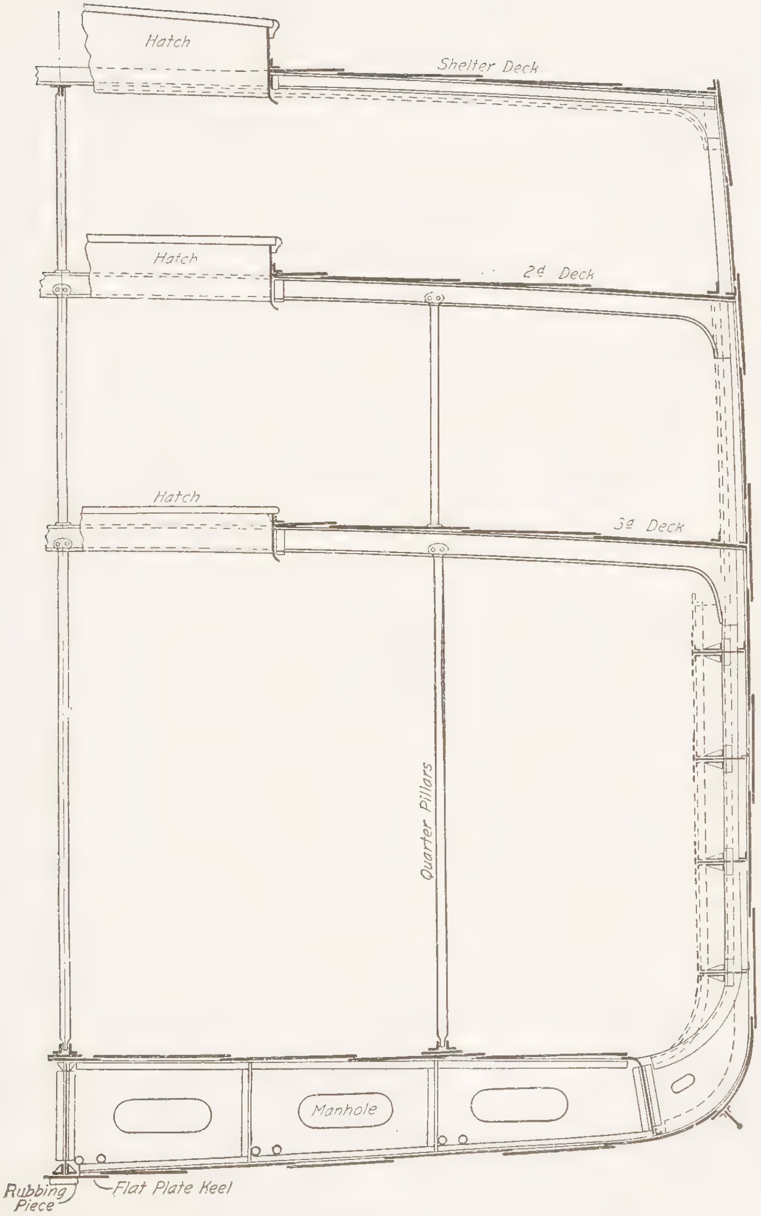

Hatch
Shelter Deck
Hatch
2d Deck
Hatch
3d Deck
Quarter Pillars
Manhole
Rubbing Piece
Flat Plate Keel

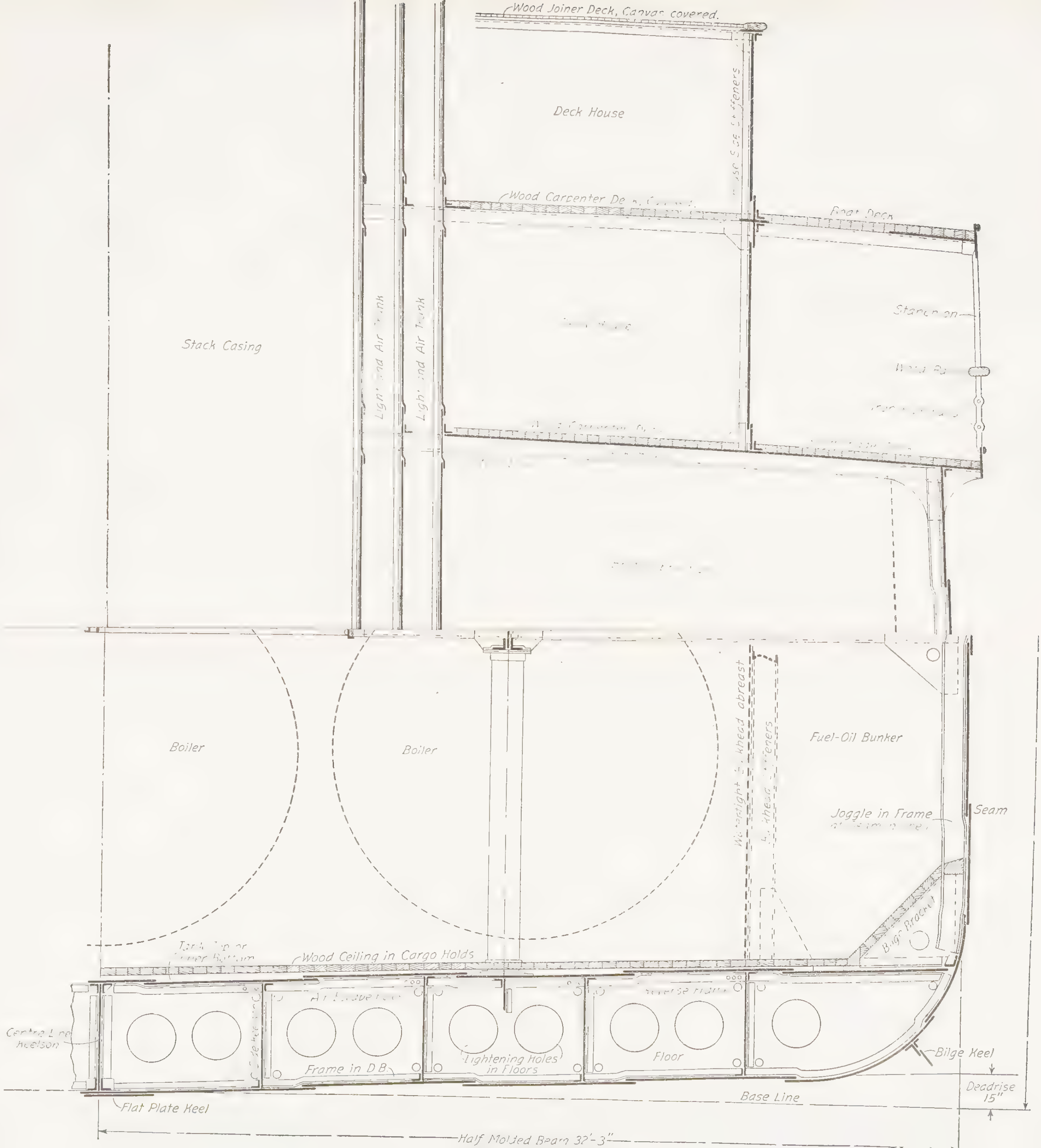
FIG. 10

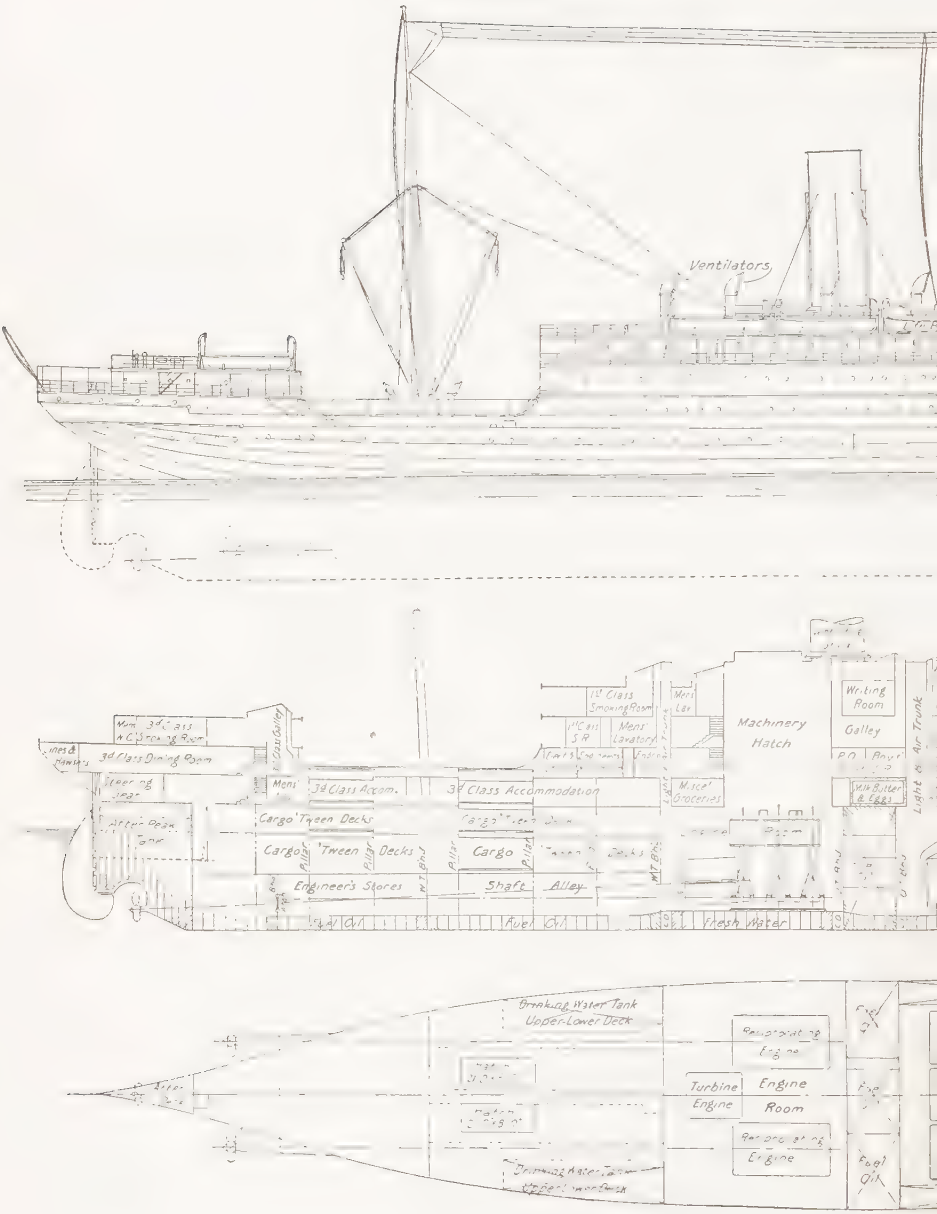
21. The use of the term *shelter deck* in shipping literature is now somewhat indefinite, since the present-day shelter-deck vessel as built in the United States differs from the three-deck, or full-scantling, vessel only in being of slightly lighter construction, and therefore being not allowed to load so deep in the water as a full-scantling vessel of the same dimensions. The permanent opening referred to in the definition just given is not provided, as under the United States rules for measurement of tonnage such openings do not give the tonnage advantages that they do under the rules of some foreign countries. What these advantages are will be understood from the following explanation.

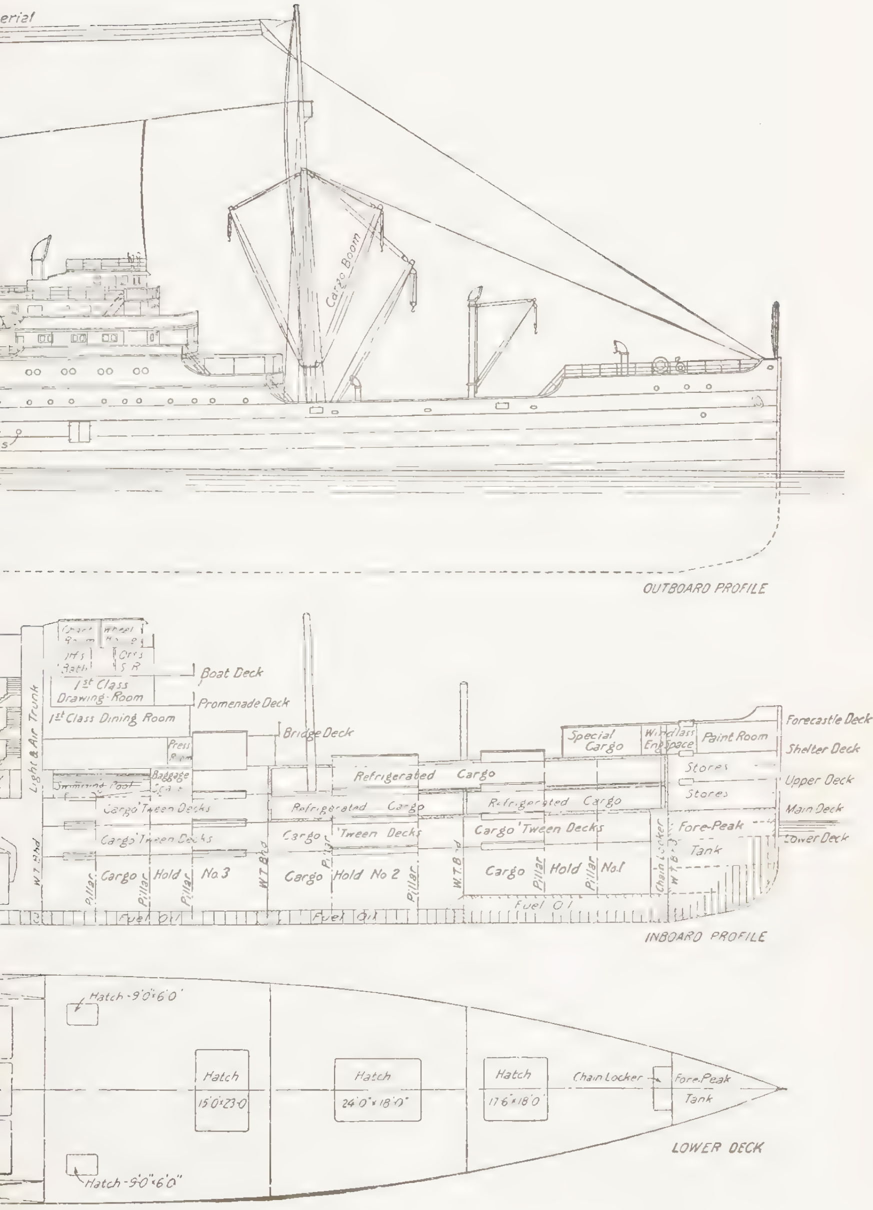
22. Tonnage is an index or measure of a vessel's interior volume, and this volume is determined by certain arbitrary rules that are the same for all vessels and that give approximately the internal volume. As certain charges are based on tonnage, it materially affects the cost of operating a vessel.

Gross tonnage, as its name implies, is a measure of a ship's total internal volume with a few deductions. The **net tonnage** is a measure of the earning volume of a ship, and is obtained by deducting from the gross tonnage the tonnage of the crew spaces, an allowance for machinery space and fuel bunkers, and other spaces necessary for working the ship.

In tonnage calculations, a **ton** is 100 cubic feet; that is, a vessel of 10,000 gross tons has an internal volume, calculated by the tonnage rules, of 1,000,000 cubic feet. There have been various types of vessels devised by which the volume of a vessel as defined by these rules could be made to appear less than was actually the case. The shelter-deck vessel is of this class. In Great Britain, if there is an opening in the shelter deck of not less than a minimum prescribed size and there is no permanent means of closing it, the space between the shelter deck and the second deck thus being directly open to the air, this space is not included in the tonnage. The American tonnage rules, however, do include this space, and the same rule also applies to a bridge erection with no permanent means of closing the ends.


Wood Joiner Deck, Canvas covered.
Deck House
Wood Carpenter Deck
Boat Deck
Stack Casing
Stanchion
Boiler
Boiler
Fuel-Oil Bunker
Joggle in Frame
Seam
Bilge Bracket
Wood Ceiling in Cargo Holds
Lightening Holes in Floors
Frame in D.B.
Floor
Bilge Keel
Deadrise 15"
Base Line
Flat Plate Keel
Half Molded Beam 32'-3"


Ventilators
1st Class Smoking Room
Mens Lav.
Machinery Hatch
Writing Room
Galley
1st Class S.R.
Mens Lavatory
Light & Air Trunk
3d Class Dining Room
Mens
3d Class Accom.
3d Class Accommodation
Misce' Groceries
Milk Butter & Eggs
Cargo 'Tween Decks
Cargo
Pillar
'Tween
Decks
W.T. Bhd.
Engineer's Stores
Shaft
Alley
Fuel Oil
Fresh Water
Drinking Water Tank
Upper-Lower Deck
Turbine Engine
Engine Room
Engine
Fuel Oil



erial
Cargo Boom
OUTBOARD PROFILE
Boat Deck
Promenade Deck
Bridge Deck
Forecastle Deck
Shelter Deck
Upper Deck
Main Deck
Lower Deck
1st Class Drawing Room
1st Class Dining Room
Light & Air Trunk
Baggage
Special Cargo
Paint Room
Stores
Stores
Refrigerated Cargo
Refrigerated Cargo
Refrigerated Cargo
Cargo 'Tween Decks
Cargo 'Tween Decks
Cargo 'Tween Decks
Cargo 'Tween Decks
Fore-Peak Tank
Chain Locker
W.T. Bhd
Cargo Hold No 3
Cargo Hold No 2
Cargo Hold No.1
Pillar
Fuel Oil
Fuel Oil
Fuel Oil
INBOARD PROFILE
Hatch - 9'0"×6'0"
Hatch 15'0"×23'0"
Hatch 24'0"×18'0"
Hatch 17'6"×18'0"
Chain Locker
Fore-Peak Tank
Hatch - 9'0"×6'0"
LOWER DECK

23. The full-scantling, or three-deck, vessel and the shelter-deck vessel are the usual types of vessels built today for general cargo purposes, though single-deck vessels are used for carrying coal, lumber, and other freight that can be stowed deep without being damaged. The larger ocean freight vessels in service at the present time have at least four full-length decks, and if constructed for the combined freight and passenger services there may be two or three tiers of superstructures above the upper continuous deck.

24. Passenger and Freight Steamer for Panama Canal Traffic.—Figs. 11 and 12 illustrate the construction and arrangement of a vessel designed with particular reference to the traffic through the Panama Canal. Fig. 11 is a midship section, and Fig. 12 shows an outboard and an inboard profile of the ship and a plan of the lower deck, *outboard* as here used meaning the outside of the vessel and *inboard* meaning the inside. As ordinarily used, the direction inboard is toward the center line of the vessel and outboard is away from the center line.

The vessel's length is 500 feet, beam 64 feet 6 inches, depth, to the shelter deck, 42 feet, and she has four full decks—the lower, main, upper, and shelter decks. The space between the shelter deck and the upper deck, as shown in Fig. 12, is devoted to passenger accommodations and the stowage of stores and refrigerator cargo. It will be noted that this vessel, being intended to carry miscellaneous cargo and package freight, has lower-deck beams and plating, there being no necessity for keeping the hold without subdivision, other than bulkheads, below the main deck; in vessels where the requirements of the service are different, this deck is often omitted. For all decks below the boat deck, there is a beam on every frame. The pillars, or stanchions, are spaced 15 feet apart. The frames are spaced 24 inches apart at the peaks, 30 inches between the forward peak and one-fifth length forward, and 36 inches elsewhere. Below the main deck there are three web frames on each side of the engine room and two on each side of the boiler room. To strengthen the vessel amidships,

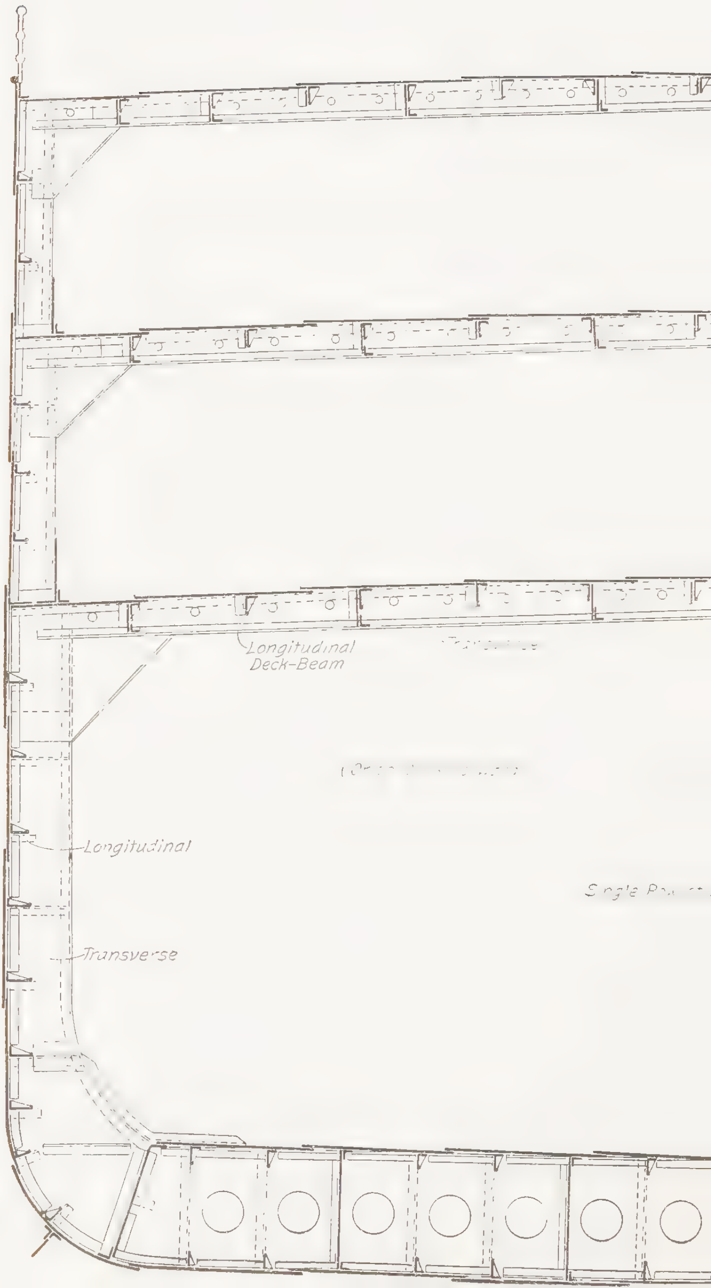
web frames are introduced into the framing from the main deck up to the promenade deck.

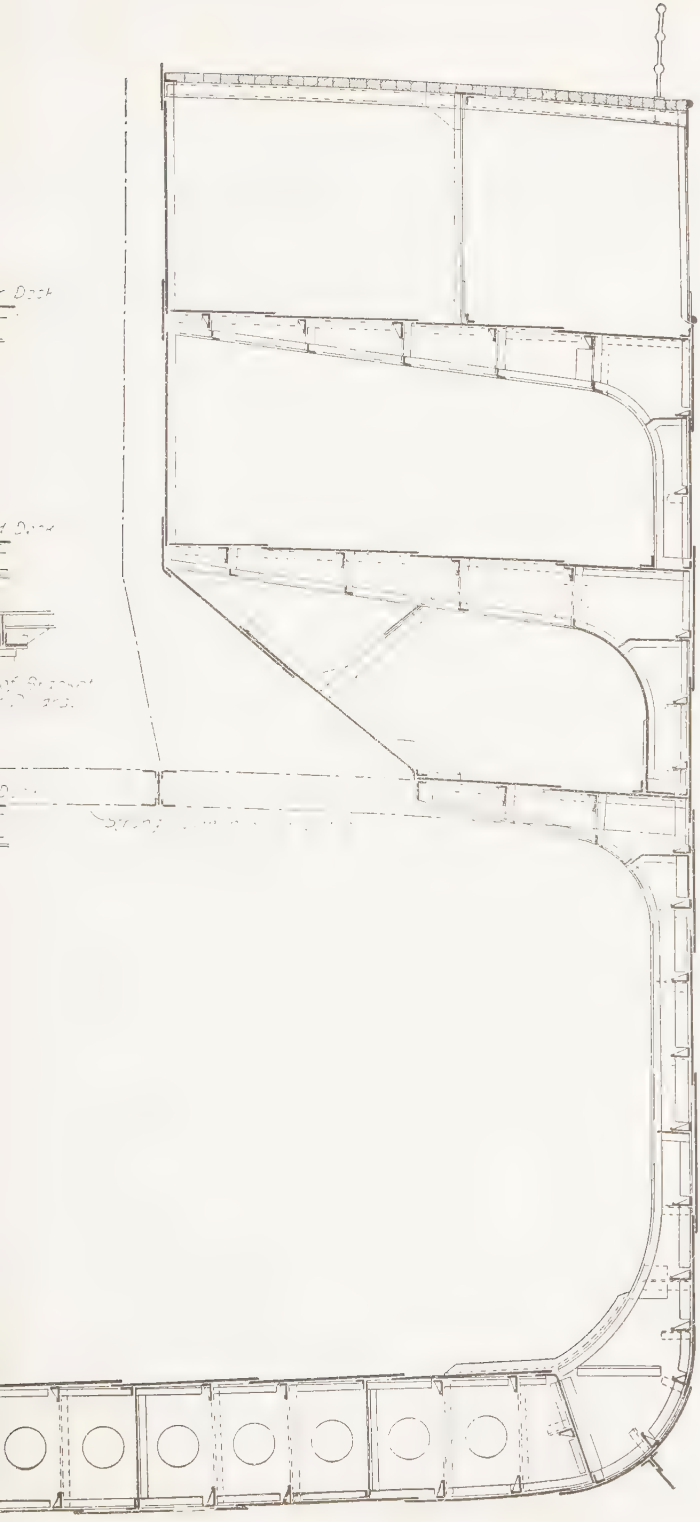
The outboard profile in Fig. 12 shows the superstructures usual for a combination freight and passenger steamer. There is a forecastle, which is used for stowage purposes, and the poop and the after part of the 'tween decks under the shelter deck are devoted to third-class passenger accommodations. There are no second-class rooms. The first-class passenger accommodations are amidships between the upper and shelter decks and above the shelter deck in the amidship superstructures, of which there are three tiers covered by the bridge, promenade, and boat decks. The wheel house and chart room are on a short deck one tier above the boat deck. The light and air hatches and the stack casing are enclosed by the surrounding superstructures. It is seen at a glance that the number of superstructures on this vessel is much greater than in case of the ordinary single-deck well-deck steamer shown in Fig. 8.

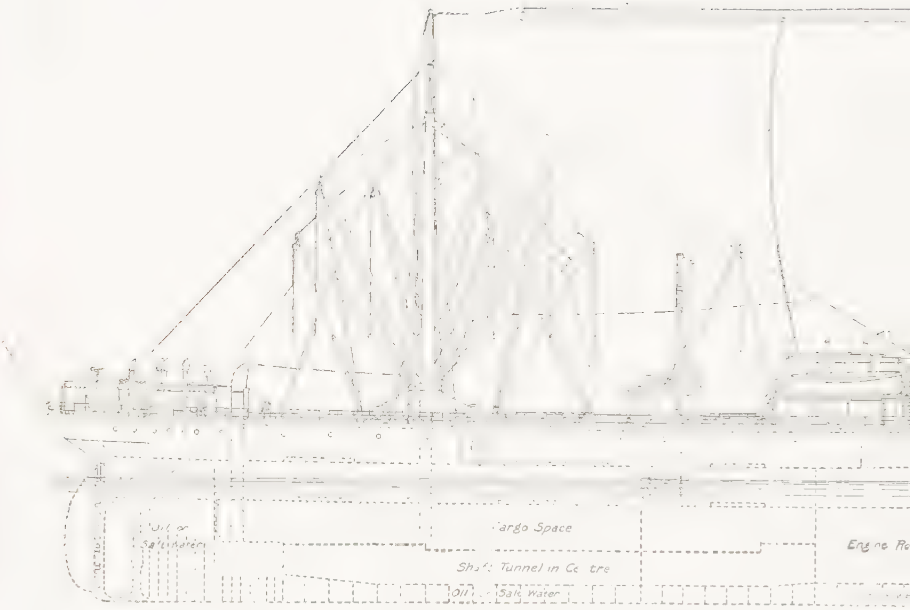
The inboard profile in Fig. 12 shows the use to be made of each of the subdivisions of the above-deck and underdeck spaces. The plan of the lower deck shows the location of the several hatches. The vessel is to use fuel oil carried partly in the double bottom and partly in a large 'thwartships tank between the engine and boiler rooms. There are three propellers, the side propellers being driven by reciprocating engines, the center screw having a turbine engine.

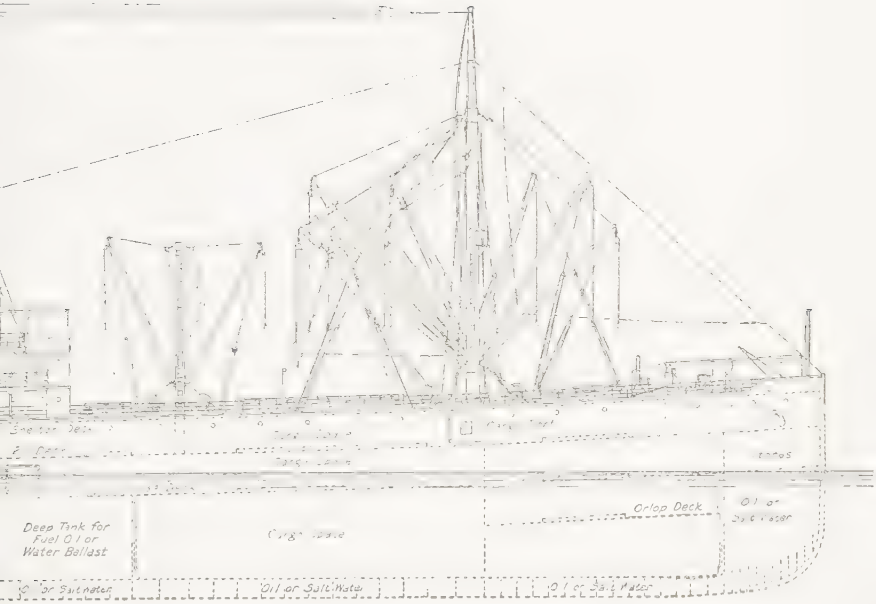
A vessel of the type illustrated by Figs. 11 and 12 has a speed of 15 or 16 knots per hour—a knot being 6,080 feet—and has too high construction and operation costs for the transportation of heavy or low-grade freight. It is intended for the transportation of high-grade, miscellaneous, and express freight at such speed—14 or 15 knots—as must be maintained by a vessel in the passenger service through the canal.

25. Freight Steamer for General Ocean Traffic. Fig. 13 gives midship section and Fig. 14 a profile of one of the eight vessels constituting the 1912 and 1913 additions to


Longitudinal
Deck-Beam
Longitudinal
Transverse




Cargo Space
Shaft Tunnel in Centre
Oil or Salt Water


Deep Tank for
Fuel Oil or
Water Ballast
Orlop Deck
Oil or Salt Water

74530

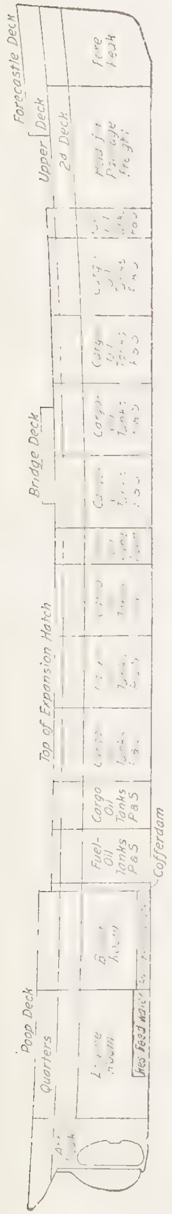


Fig. 15

the fleet of the American-Hawaiian Steamship Company. The vessels of this type are designed solely for the transportation of freight, and are operated at a speed of about 11 to 12 knots per hour. The vessels are about 415 feet long between perpendiculars, 53 feet 6 inches beam, and 39 feet 6 inches molded depth to the shelter deck. Each vessel will carry about 10,000 tons dead weight.

The main structural features of these vessels are shown in Fig. 13. The ship is a shelter-deck vessel, with a cellular double bottom, and built on the Iserwood system of framing. In this system, the main frames run longitudinally and are supported by the bulkheads and by transverses or webs spaced from 8 to 10 feet apart. Deck beams are also longitudinal and supported like the frames. This system gives, for the same strength, a somewhat lighter steel structure than other systems.

The left half of Fig. 13 is a section forward and aft of the engine room and boat deck; while the right half of the drawing gives the section through the engine room. The crown of the engine room is at the second deck, above which the air hatch extends through the shelter and boat decks.

The vessel is without forecastle. Above the shelter deck, however, there are two part-length decks—the boat and bridge decks. Crew accommodations are provided in a short poop house and in the midship house under the boat deck. The officers' quarters are on the boat deck, and there is a bridge above the boat deck. Since this vessel is designed solely for the freight service, the number of above-deck erections is far smaller

than in the case of the combination freight and passenger steamer illustrated in Figs. 11 and 12. The profile shows the location of the orlop deck and of those above, of the engine and boiler rooms, and of the deep tank. The vessel is a single-screw steamer with oil-burning, reciprocating engines. Fuel oil is ordinarily carried in the large deep tank placed athwartships forward of the boilers. The double-bottom and the peak tanks are ordinarily used for water ballast except when long-distance steaming requires their use for fuel oil.

26. Oil-Carrying, or Tank, Steamer.—Figs. 15 and 16 show in outline the usual type of vessels employed for carrying oil in bulk. The machinery is placed aft as it is in present-day colliers. The main tanks are made narrow at the top in the expansion trunk to secure stability with a free surface. If the free surface, or top, of the oil extended clear across the vessel, the stability would be seriously impaired. About 95 per cent. of the space is filled; the remaining 5 per cent. is left empty, to provide for expansion. Hence, this narrow part is called an expansion

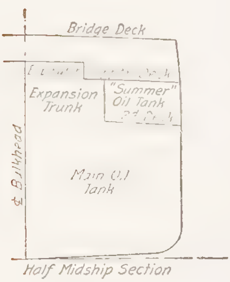


FIG. 16

hatch or the part below the upper deck an expansion trunk. The tanks do not exceed about 27 feet in length and are separated all the length fore and aft by an oil-tight center-line bulkhead forming port and starboard tanks, indicated by *P & S* in Fig. 15. The oil extends clear to the sides and bottom of the vessel, there being no double bottom except under the machinery where the space is used for reserve feed-water. The *summer* tanks, as they are called, extend along the second deck at each side of the expansion trunk abreast the fuel and cargo-oil tanks and are used to carry oil when it is of such a density or specific gravity that the quantity carried in the main tanks would not bring the vessel to her load draft. They can be used when carrying gasoline. The fuel is distributed forward and aft to prevent the excessive trim which

would result if all the fuel were consumed from one end. The cargo is loaded and unloaded through large pipes running the whole length of the cargo spaces and near the bottom of the vessel. Unloading is usually accomplished by means of the cargo oil pumps located in the space amidships. The cofferdam is a small compartment into which any leakage from adjoining oil tanks collects; in this case it insulates the boiler room from the fuel tank and prevents any leakage from getting into the boiler room. Not always, however, are fuel tanks so separated from the boiler room; but it is the safer way.

There are many other special types of merchant vessels designed for particular trades or cargoes, but the foregoing will serve to illustrate to the uninitiated some of the general features of our merchant marine.

PRINCIPAL DIMENSIONS OF A SHIP

27. To one unacquainted with ships, the dimensions convey a better idea of size than does the tonnage, which is the marine term usually employed to denote size.

28. The **three dimensions** of a ship are length, breadth, and depth. The points at which these measurements are taken, as referred to in the explanations that follow, are indicated in the profile and cross-section in plate entitled *Lines, 1051*.

29. There are three different lengths to be considered, as follows:

1. The *length between perpendiculars,* sometimes called *length on load water-line,* **load water-line** (abbreviated L. L.), meaning the water-line at which a vessel floats when carrying the designed load of cargo, fuel, etc. Length between perpendiculars (abbreviated L. B. P. or L. P. P.) is measured on the load water-line, from the fore side of the stem to the after side of the stern post. The **forward perpendicular** is the vertical line through the intersection of the load water-line with the fore side of the stem; the **after perpen-**

dicular is the after side of the stern post at the load waterline.

2. The *length over all,* which is the extreme length from the foremost part of the stem to the extreme after part of the hull. Abbreviation is L. O. A.

3. Another length adopted by some classification societies is the horizontal length from the fore side of the stem at the upper deck to the after side of the stern post.

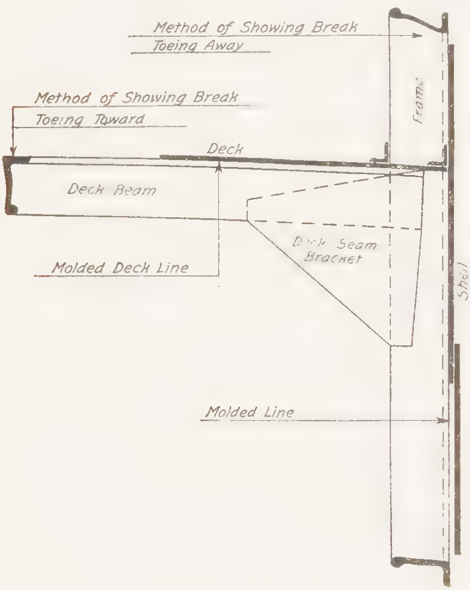


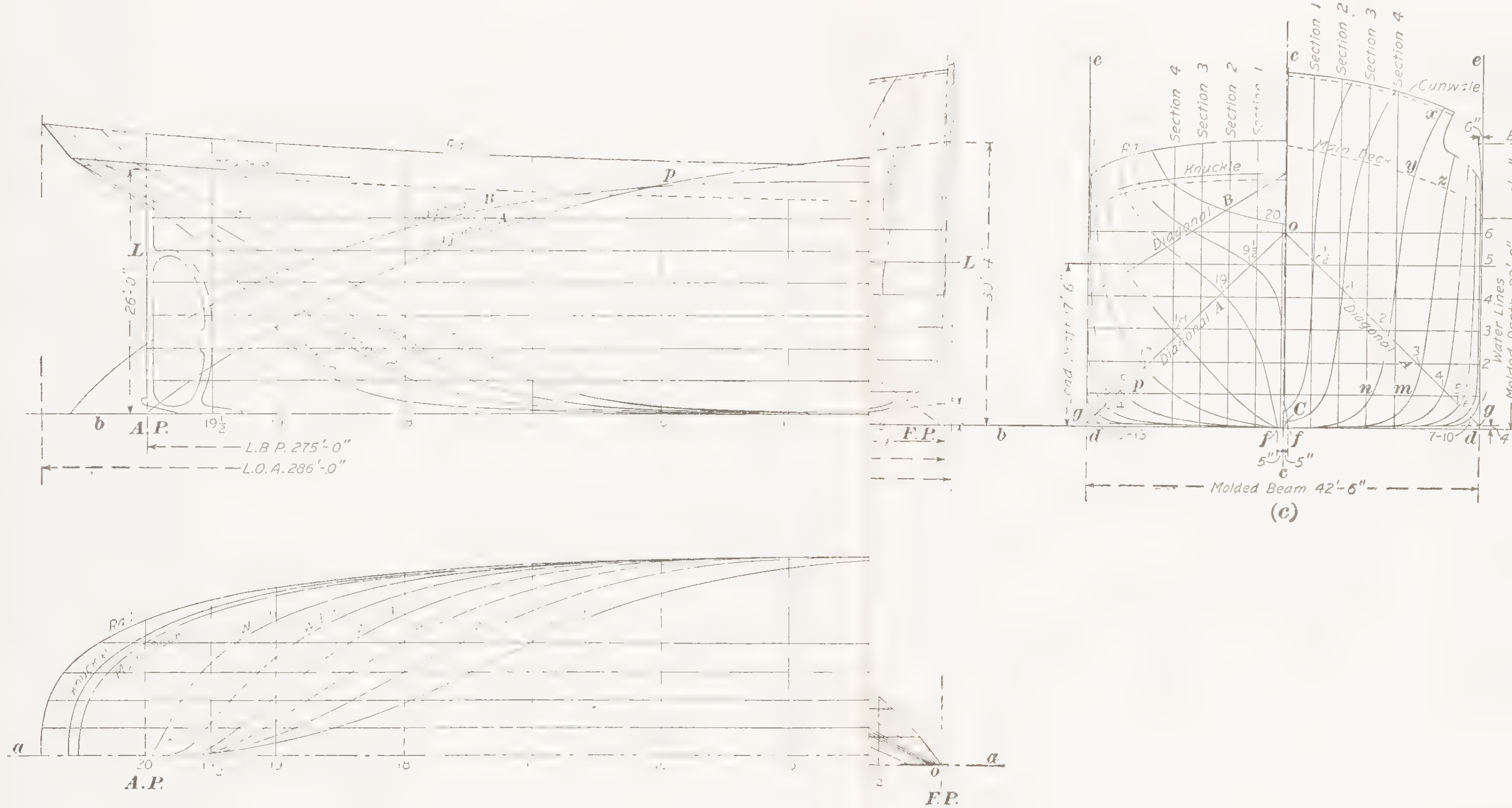
Fig. 17

When in the following discussions the length of a ship is mentioned without qualification, the length between perpendiculars will be meant.

30. Breadth, or beam, is usually measured over the frames—not the outer shell at the widest part of the vessel. This is the *molded breadth,* or *molded beam.*

31. Depth.—The *molded depth* is measured half way between the perpendiculars and from the top of the upper deck beam at the side to the base line of the vessel, or the upper side of the keel plate.

32. The **molded line** to which the molded breadth and the molded depth are measured is plainly shown in Fig. 17, which represents the intersection of a deck beam with the side frame of a ship. The points between which the molded depth and the molded breadth are measured are well shown in Fig. 11.



(c)

LINES

DRAWN BY

DATE

1051

DRAWING PLATES

33. Ship drafting requires not only a knowledge of structural and mechanical drafting, but also an understanding of certain special work peculiar to the business. The purpose of the following series of drawing plates is to illustrate the various classes of this work.

PLATE 1051, TITLE: LINES

34. One of the first drawings that is made for a proposed vessel is that showing her shape, or form, and this drawing is called the **Lines.** The making of it requires the use of facilities and appliances not usually possessed by the individual, therefore the making of it will not be required here, but it will be carefully described in order that the draftsman may become familiar with it and understand the manner in which the shapes are represented and the meaning of the various lines.

The Lines drawing, as shown on the plate, is a projection drawing and shows the molded form of the vessel, as it is called; that is, the form over which the shell or outer plating is placed. The lines show the surface developed by the series of frames, which are regularly spaced throughout the length of the vessel. Such a drawing is usually made on a scale of $\frac{1}{4}$ inch=1 foot, and therefore, for the 275-foot ship represented on the plate, would be nearly 6 feet long.

35. It is evident that to make such a drawing special means must be supplied for drawing the numerous curved lines of slight or irregular bend, as these lines must be what are called **fair** lines; that is, curving smoothly without humps or hollows. Such curves are drawn by the use of **battens,** or *splines.* These are thin, smooth, regular-edged strips of wood or hard rubber of square or rectangular cross-section,

those of hard rubber often having a rectangular groove cut in the side, as shown in Fig. 18. These battens can be bent to any required curves, and are held in place on the drawing paper by lead or iron weights, weighing from 2 pounds upwards, into each of which is cast a piece of heavy wire having a chisel, or wedge, point that fits into the groove of the rubber batten, as shown in Fig. 18, or rests on the top of the wooden one.

The battens are of various lengths and cross-sections, and they may be of constant cross-section or they may taper. For regular curves, those of constant cross-section are used. For lines that are flat at one end and curved at the other, a batten

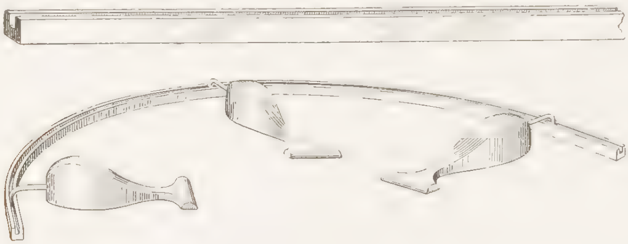


FIG. 18

tapered at one end may be used; for lines that are flat or slightly curved at the ends and sharply curved in the middle, a batten thick at both ends and tapering toward the middle is used.

Also, curved lines may be drawn by means of *ship curves* of forms like those shown in Fig. 19. Such curves are made of wood, rubber, or celluloid.

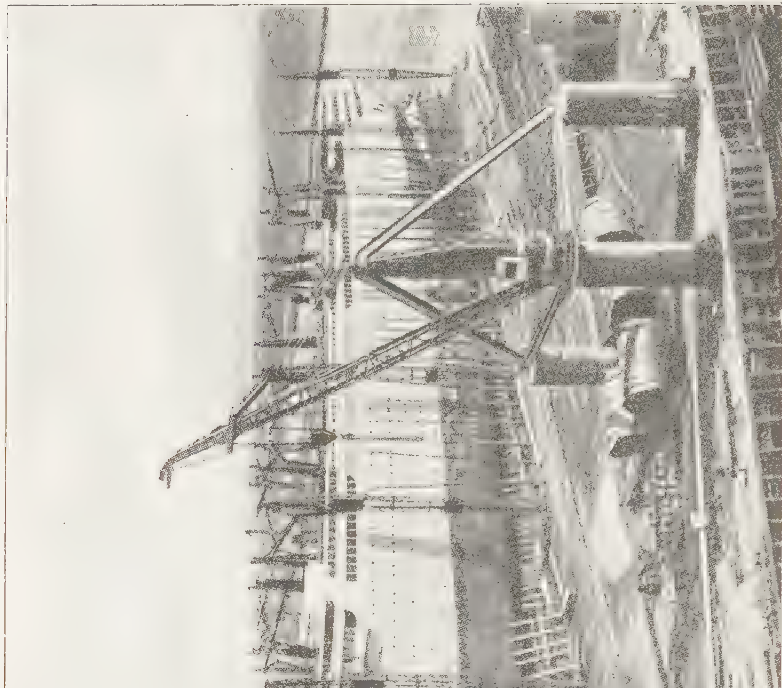
In absence of proper splines or ship curves, a substitute may be made by laying a piece of medium-weight bristol board on a board and cutting a curve by a sweeping stroke with a sharp knife. Several attempts may be necessary, but usually some part of the curve so cut can be found that is suitable for the desired lines.

The other tools required for ship drafting are an accurate straightedge, preferably of steel, accurate triangles, and the usual mechanical-drawing tools. As a set of battens and ship curves is rather expensive, such apparatus is not often owned by the draftsman, but is usually supplied by the drawing room.

which is one of the reasons that the student in this case is not required to draw the Lines plate.

FIG. 19

36. Fig. 20 is a picture of an ocean steamer on the launching ways, where the form and outline of the ship, both above



and below water-line, can be plainly seen. It will help to make plain a number of features that will be referred to in connection with the projection drawings shown on the plate entitled Lines.

37. The Lines drawing, shown on Plate 1051, consists of three parts—a plan (a), usually called the water-line plan; an elevation, or *sheer* drawing, (b); and an end view, or section, (c) known as the *body plan.*

On the plate, the base lines $b\ b$ and $d\ d$ are in the same straight line, and the center line $a\ a$, for view (a), which is for half the vessel, is parallel to $b\ b$. As a vessel is symmetrical about the center line, only one side needs to be drawn.

The center line $c\ c$ of the body plan (c) is perpendicular to the base line $d\ d$. Side lines $d\ e$ are drawn perpendicular to $d\ d$ and distant from $c\ c$ a distance equal to half the molded beam. In view (b) are drawn elevations of water-lines, equally spaced and parallel to the base line $b\ b$; these are marked *W. L. 1, W. L. 2, W. L. 3,* etc., and are also projected to view (c) and numbered *1, 2, 3,* etc. on the right-hand side.

The line drawn perpendicular to the base line $b\ b$ through the intersection of the load water-line $L\ L$ and the forward side of the stem is called the **forward perpendicular,** and the point where this line cuts the base line is marked *F.P.* The after side of the stern frame is perpendicular to the base line and is known as the **after perpendicular,** and the intersection of this line continued and the base line is marked *A.P.* Points *F.P.* and *A.P.* are projected onto the plan (a) at points *0* and *20*, respectively. The length *0* to *20*, or *F.P.* to *A.P.*, is the length between perpendiculars and is frequently expressed as *L.B.P.* or *L.P.P.* This length is divided into an even number of spaces, by *stations,* or *body* lines, numbered consecutively from *1* to *19*. The middle station *10* is called the midship section and is usually the fullest part of the vessel. It is also the center between perpendiculars and is expressed as *C.B.P.* or marked with the character indicated in view (b). Half stations, as shown, are marked at the ends of the vessel.

In view (c), equally spaced from $c\,c$ on each side, are section lines marked *Section 1, Section 2,* etc. These are also shown as straight lines in the plan (a). On each side of C on base line $d\,d$ is laid off the half siding $C\,f$ and from f are drawn the straight lines $f\,g$. The distance $d\,g$ is known as the **dead rise,** or *rise of the floor.* This rise is to give a drainage for water toward the center line of the vessel. The half siding will be explained later.

38. The *water-lines 1, 2, 3, 4, 5, 6* shown in view (a) are horizontal sectional views representing the boundaries of the figures generated by horizontal planes cutting the hull at different elevations; they are therefore projected as straight lines in the elevation (b) and in the cross-section, or body plan (c), in which they represent the lines of water levels on the side of the ship.

The stations, numbered *0* to *20*, represent vertical transverse sections, and they therefore appear as straight lines in the elevation (b) and the plan (a); in view (c) they appear as curved and they can be identified by the numbers at their intersections with *Diagonal A*.

The *sections 1, 2, 3, 4* represent vertical longitudinal sections, which are straight lines in views (a) and (c) but are curved in view (b), these curves being called *buttocks*.

To make plain the reason for, and the meaning of, these various curves, Fig. 21 is given. In this is shown in perspective the form of a ship, on one-half of which the section lines, water-lines, and stations are marked in the same way as on the plate. If the ship were sliced vertically, lengthwise along the section lines, the ends of each section would have the outlines made by the curved lines seen at the bow and stern, which are the same as the curves shown in view (b) of the plate. Such a slice at section *4* is shown in the longitudinal section in Fig. 21. The curves of the section lines in view (b) represent merely the boundaries of the figures generated by vertical planes cutting the curved hull of a ship longitudinally parallel with the center line.

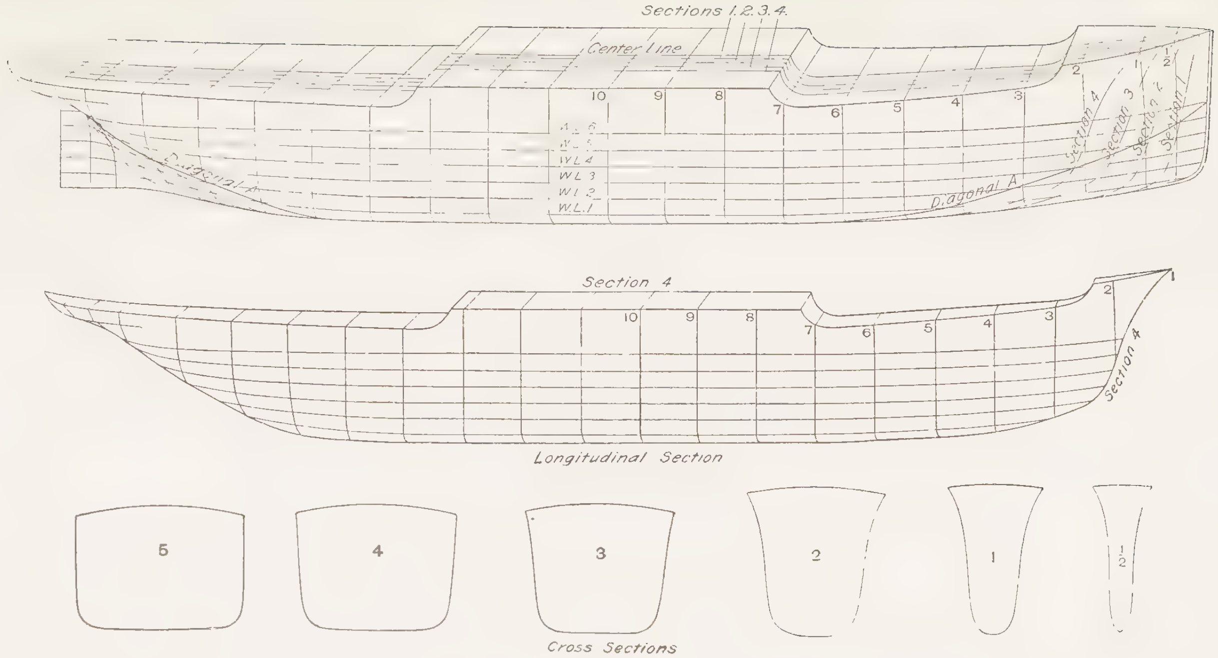

Sections 1.2.3.4.
Center Line
Section 4
Section 3
Section 1
Diagonal A
WL 4
WL 3
W.L.1
Section 4
Longitudinal Section
Cross Sections
5
4
3
2
1
½

Fig. 21

The six cross-sections in Fig. 21 show the outlines made by cutting the ship transversely at stations of corresponding numbers; and it will be noted that the outline of each figure corresponds to the curve having the same number in view (*c*) of the plate; for example, the right-hand outline of the cross-section numbered *2* corresponds to the line $x\ y\ n\ C$ of view (*c*) and this line represents station *2* in view (*b*). The curves in view (*c*) therefore represent the boundaries of the figures generated by vertical planes cutting the hull transversely at the various stations.

39. The top deck of a vessel (in these views marked *Main Deck*) is usually crowned, or **cambered;** that is, the deck is higher at the center than at the sides in order to make water drain to the sides of the deck. The intersection of the main deck and the shell appears in all views. The intersection of the deck and the transverse planes is not shown.

The rail, or gunwale, is the top of the outer plating of the vessel that extends up above the deck line. The lines of the gunwale are usually parallel to the deck line. The curvature of the rail and the deck lines in the elevation is called **sheer,** from which the elevation is sometimes called the *sheer plan.* The difference between the height of the deck at any point and the height above the base line at the middle of the length of the vessel is called the **sheer** at that point.

40. In the body plan, the midship station is outlined to right and left, so that the body plan appears symmetrical. As the cross-sections at all stations are symmetrical about a vertical center line, one side only need be drawn; therefore, in the body plan, the stations shown at the right of the center line are those forward of amidships and those to the left are aft of amidships. Likewise, the water-lines in view (*a*) are drawn to one side only of the center line.

The top, or main-deck, line is drawn on the water-line drawing (*a*), and at the after part the rail line is shown. Attention is called to the fact that the lower water-lines are finer, or sharper, aft than forward, while the upper water-lines are the reverse and the deck line is very blunt aft. The

projection of the vessel aft of the after perpendicular is called the **overhang,** or *counter.* The purpose of this is to give protection to the rudder and propeller; as this part is not in the water, it adds nothing to the resistance of the vessel, and

Fig. 22

by making the overhang wide much deck room and interior volume are gained.

Fig. 22 shows the after part of the vessel and gives a good idea of how the water-lines curve in to the center line at the stern. When the vessel is afloat, the depth of water she draws can be read from the vertical line of figures near the stern.

41. The sheer of the deck is projected to the body plan (*c*) by projecting from view (*b*) points representing the heights of the deck at its intersection with the different stations. Thus, *z* is the intersection of the main deck with station *3*, and *y* and *x* are the intersections of the main and the forecastle decks, respectively, with station *2*; other points can be located in like manner in view (*c*), each of them being placed the same distance from the center as it is in view (*a*). The curve connecting the points so located on the right-hand side will be the projection of the sheer of the deck from the midship station forward. The projection of the sheer of the deck aft is drawn in a similar manner, projections being made from whatever number of stations are necessary to outline the curve on the left of the center line.

42. For the main deck, the sheer forward is 7 feet 8 inches, being the difference between the depth at the forward perpendicular, 30 feet 4 inches, and the depth molded amidships, which is given as 22 feet 8 inches. Similarly, the sheer at the after perpendicular is 3 feet 4 inches. The vertical height between the main deck and the bridge deck, 8 feet 0 inches, is called the **deck height,** or *height between decks,* this term of course being applicable to the height between any pair of decks.

43. The **knuckle** is the line where the sloping outer surface of the after part of the ship intersects the steeper surface of the hull that extends up from slightly above the deck. In view (*b*) of the plate, the knuckle disappears forward of station *18½*, beyond which point there is no break in the fair surface from bottom to rail. In Fig. 22 the line of the knuckle can be seen ending at the point *a*.

44. The outward reverse to stations ½, *1*, and *2* above *W. L. 6* is called the **flare.** This is seen in Fig. 20 where the vertical derrick nearest the bow of the ship casts a shadow that apparently is curved backwards at the upper part as the result of the outward flare of the ship's hull at that point. Farther aft it will be noticed that the upper parts of such shadows are straight, though the bottoms of the shadows are

curved forwards on account of the inward curve of the lower part of the ship.

45. On the plate, from stations *6* to *15* above *W. L. 6*, the sides of the ship are represented as sloping toward the center line of the ship. This slope is called the **tumble-home,** and in view (*c*) the tumble-home is shown as 6 inches at the *Bridge Deck*, this being the horizontal distance from the side line *d e* to the deck.

46. The full rounded shape at the lower part of stations ½, *1*, and *2* is known as **club foot.**

At the bottom of the forward end of the elevation, view (*b*), the rise of the rise line of the **fore foot** is indicated as 2 feet 4 inches.

The sign or character, shown just below station *10* in view (*b*) indicates the location of the midship section or half length; this is sometimes called C. B. P., *center between perpendiculars.*

47. Diagonals.—The diagonals *A* and *B* in the body plan (*c*) represent intersections of inclined planes cutting the ship's center line and the shell at the heights indicated. The elevations at which such planes cut the center line and the shell may be chosen as circumstances require. Thus, *Diagonal A* represents the intersection of a plane cutting water-line *6* through the whole length of the ship's center line and also cutting the lower outer corner, or bilge, of the ship, and the intersection of this plane with the shell of the ship produces a curve as shown by *Diagonal A* in view (*b*).

In Fig. 21, the line where such a plane would cut the shell of the ship is indicated by the heavy curved line marked *Diagonal A*. On the plate, this curve is plotted on the elevation (*b*) for convenience, and it should be remembered that the offset, or measurement, of the diagonal at each station is the distance from the line *b b* to the curve. For example, in view (*c*), the length *o p*, which is the distance on the *Diagonal A* and *o* to the shell of the ship at station *16*, is the same as the distance *16–p* in view (*b*). In the same way the measurement on *Diagonal A* in view (*c*) from *o* to *17* is

the same as vertical distance in view (*b*) from the base line *b b* at station *17* to the curve marked *Diagonal A*.

Diagonal B is drawn in a like manner to show the curve formed by the intersection of the shell of the ship with a plane cutting the center line of the ship at the elevation of the highest point of the knuckle and also cutting the shell at the water-line *4*, these points being first determined on the body plan, view (*c*).

The curves, as *Diagonals A* and *B*, are sometimes shown on the plan instead of the elevation; in such case they are laid off from the base line *a a* in the same manner as they were from base *b b* in the elevation.

48. All the water-lines, body lines, section lines, and diagonal lines must be fair or smooth and all points like *m, n, x, y*, and *z* must correspond in all views. When these lines are fair, then the surface of the hull is fair and free from humps or hollows.

BEAM CAMBERS

49. As previously stated, the deck beams are cambered to drain the water toward the sides. Formerly a theory was advanced that the crowning, or arching, of the beam made it stronger. But as an arch depends on solid abutments for strength and as the sides of a ship are not solid or backed by a fixed support, this theory is fallacious. It is not so necessary to camber decks below the top, or weather, deck, and in many modern vessels this is not done, or if it is done only a small camber, perhaps 2 inches, is given. This small amount is to counteract any irregularities in erecting and to prevent a sag to the deck such that water might collect in the center.

The camber is expressed as so many inches in the breadth of the deck or in fractions of an inch per foot of beam. If the breadth of the deck is 48 feet and the camber 12 inches, the expression would be 12 inches in 48 feet or $\frac{1}{4}$ inch per foot. This figure is the customary camber in merchant vessels, but in torpedo boat destroyers it usually runs much higher —even 15 inches in 30 feet.

Several ways of laying out the camber are available and three will be described here.

50. First Method.—Lay down a straight line, as *a b*, Fig. 23, equal to the half beam of the deck and drawn to any convenient scale. At *a* erect a perpendicular *a c* equal in height to the given camber and drawn to the same scale as *a b*. With *a* as a center and a radius equal to *a c* draw the quadrant *c i g* and divide this into any number of equal parts, say four, by points *h, i,* and *j*. Divide *a g* and *a b* into the same number of equal parts at *d, e,* and *f*; and at *k, l,* and *m,* respectively. Draw *d h, e i,* and *f j*. At *k, l,* and *m,* erect perpendiculars *k n, l o,* and *m p* equal in length, respectively, to *d h, e i,* and *f j,* thus locating points *n, o,* and *p*. Through the points *c, n, o, p,* and *b* draw, with a ship curve or with a batten and weights, the curved line which represents the camber or deck beam. The center of the ship is at *c,* and *b* is the side of the deck, there-

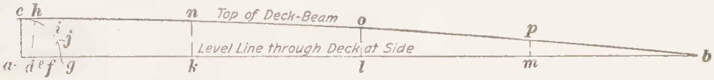


Fig. 23

fore, *c b* is one-half of the beam, the other side being exactly the same and of course to the left of *a c*. The line *b o c* represents the top of the deck beam, or the *molded line* of the deck.

51. In order to give more accurately the camber at any point or to determine the distance that any point on the deck is below the deck at the center line of the ship, it is desirable that the diagram just described be drawn with the vertical distances to a larger scale than the horizontal distances, as the exaggerated curve so produced is more easily and accurately read or measured. This is shown in Fig. 24, where the camber is 15 inches in 44 feet.

Here the total camber *a c* is drawn to eight times the scale of the half beam *a b;* and as the quadrant *c i g* is eight times the size, all the vertical dimensions are equally enlarged. It is the custom in actual practice to make *a c* full size, and then the heights *k n, l o, m p,* etc., are full size. It is convenient to

add to the diagram by drawing $c\,q$ parallel to $a\,b$ and dividing this line into parts corresponding to feet from the center c. Then $q\,b$ is drawn parallel and equal to $a\,c$ and divided into inches, and vertical and horizontal lines are drawn through the feet and inch marks. The camber at any distance from c may then be read off directly in inches. For example, at 12 feet from c the diagram shows the camber to be $4\frac{3}{4}$ inches.

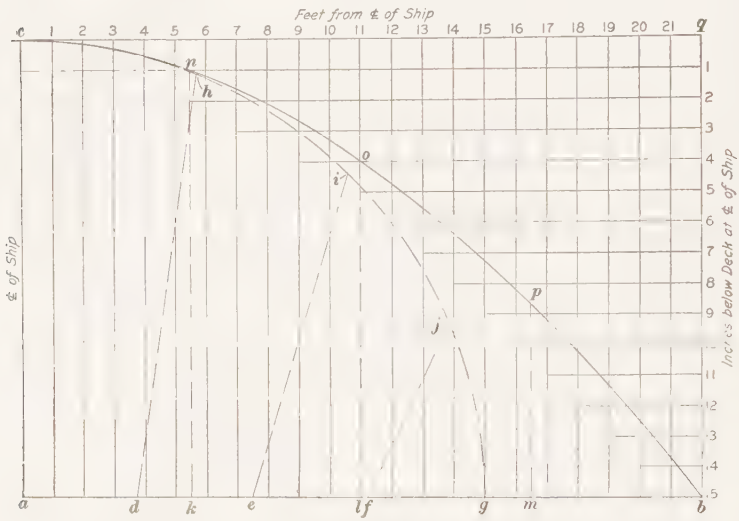


FIG. 24

A camber curve divided into squares in the manner explained, but without the construction part, is convenient to have in the office for laying out bulkheads, deck houses, bridges, etc.

52. Where decks are parallel transversely—that is, have the same camber—but have different amounts of tumble-home, the vertical height between the outer edges of the decks at the side of the ship will be greater than at the center, since, though the curve per foot is the same, the lower deck, being the wider, has more feet in which to curve downwards. This is illustrated in Fig. 25, which represents the half width of two decks each having a camber of 15 inches in 44 feet. At the ship's center the vertical distance between decks is 8 feet. The tumble-home is 7 inches, making the half width of the upper deck 22 feet

—7 inches=21 feet 5 inches; the half width of the lower deck, as shown, is 22 feet.

53. The diagram, Fig. 24, shows the amount of downward curve of a deck at different distances from the center line for a camber of 15 inches in 44 feet. Thus, for the half width 21

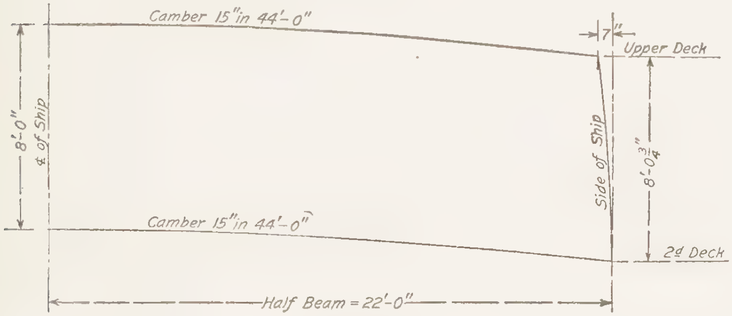


FIG. 25

feet 5 inches, the amount of downward curve is $14\frac{1}{4}$ inches; for a half length of 22 feet, it is 15 inches; therefore, at its outer edge, the second deck has curved downwards $15-14\frac{1}{4}=\frac{3}{4}$ inch

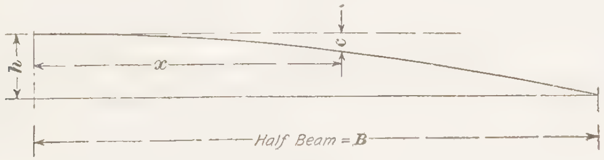


FIG. 26

more than the upper deck at its outer edge, and the height between decks is therefore 8 feet$+\frac{3}{4}$ inch=8 feet $\frac{3}{4}$ inch.

54. Second Method.—In Fig. 26, let B be the half beam in which h is the total camber. The camber c at any given distance, as x, from the center line is equal to $\frac{x^2}{B^2}\times h$. This camber curve is a parabola.

By this method, if $B=22$ feet, $h=15$ inches, and $x=12$ feet, $c=\frac{12^2}{22^2}\times 15=\frac{144}{484}\times 15=4.46$ inches, or $4\frac{7}{16}$ inches, nearly.

55. Third Method.—The third method of finding the camber is by means of an arc of a circle. In Fig. 27, c, h, x, and B have the same meanings as in the preceding method and R is the radius of the camber curve, or of the deck beam. For the purpose of calculation, the radius R may be considered to be made up of two parts, as c and $R-c$ or h and $R-h$. As in the preceding method, $h=15$ inches, $x=12$ feet, and $B=22$ feet.

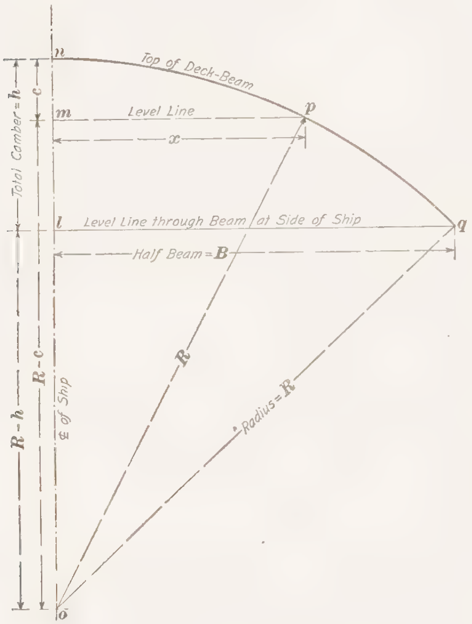


Fig. 27

The angle $q\,l\,o$ is a right angle, and the triangle $o\,l\,q$ is a right triangle; then using the notation given in the figure, by the principles of geometry, $R^2=B^2+(R-h)^2$. In this equation, all the quantities are known except R, hence it is possible to find the value of R. By algebraic methods, which need not be explained here, the equation $R^2=B^2+(R-h)^2$ can be resolved into the formula

$$R=\frac{B^2+h^2}{2\,h}$$

Then by using the values given for the letters, and expressing the value of h in feet, because all terms in a fraction like this must be in the same units, it is found that

$$R=\frac{B^2+h^2}{2\,h}=\frac{22^2+1.25^2}{2\times 1.25}=194.22 \text{ feet}$$

Now, R being known, it is possible to find the camber c for any known distance, as x feet from the center, by the formula

$$c = R - \sqrt{R^2 - x^2}$$

This formula applies for any point on the curve and can always be solved once R has been determined as described. Then, by substituting the given values in the formula, it is found that

$$c = R - \sqrt{R^2 - x^2} = 194.22 - \sqrt{194.22^2 - 12^2} = .37 \text{ foot,}$$
$$\text{or } 4\tfrac{7}{16} \text{ inches, nearly}$$

56. For those who wish to know the principles on which the formula is based, the following explanation is given:

In a right triangle whose apex is at p a known distance x feet from the center, the equation will be $R^2 = x^2 + (R - c)^2$, where c is the camber at point p and is the only unknown quantity in the expression. Solving for c, we have $R - c = \sqrt{R^2 - x^2}$, and $c = R - \sqrt{R^2 - x^2}$, as was given.

A summary of the three methods shows that by the first method the camber at a distance of 12 feet from the center is $4\tfrac{3}{4}$ inches, by the second method $4\tfrac{7}{16}$ inches, and by the third method $4\tfrac{7}{16}$ inches.

57. In place of a curved camber, a straight pitch as shown in Fig. 28 is sometimes used. The pitch is the distance

FIG. 28

the deck at the center is above the deck at the sides. A deck having a straight pitch is made with an arc of large radius at the center, and the straight slopes to the sides of the deck are tangent to this arc.

STRUCTURAL DETAILS

58. Plates.—The steel structure of a ship consists almost entirely of plates and shapes, the latter including angles, channels, bulb angles, etc. The outside plating, decks, inner bottom, bulkheads, etc., cannot of course be in one piece, so they are built up of a number of plates, which are connected by riveted

joints. Shell, decks, and inner bottoms have these plates extending longitudinally, with the strongest connection at the ends. In bulkheads the long dimension of the plates may extend vertically or horizontally.

59. Plate Joints.—Connections at the sides of plates are called *seams* and at the ends *butts*. In a lapped connection, or *lapped joint,* one plate extends over the adjacent one; in a *strapped joint* the edges of the two plates to be connected are close against each other with their surfaces flush, and the adjacent edges are covered by a narrow plate, half of it being over each of the plates connected.

A *double-strapped joint* has a narrow plate, or strap, on each side of the plates connected. The width of the strap or

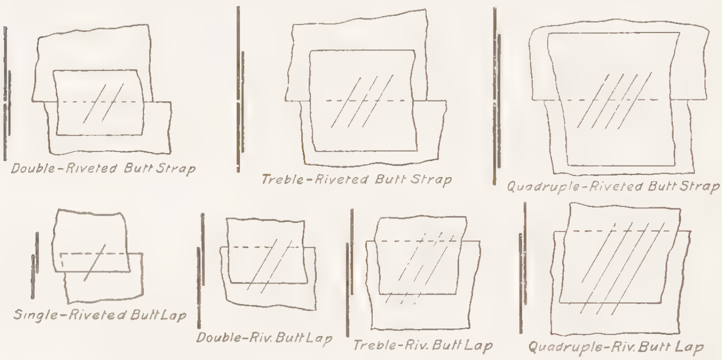


Fig. 29

of the lap depends on the number of rows of rivets and the size of the rivets, which in turn varies with the thickness of the plate. Joints are single, double, treble, quadruple, or quintuple riveted, according to whether they have one, two, three, four, or five rows of rivets. The method of indicating them on drawings is shown in Fig. 29.

60. In Fig. 30 are shown three strakes, or rows, of plates and a deck beam. Remarks concerning this will apply to similar parts of any structure. In view (*a*), edge laps are shown at *a* and *b*. At seam *a* the plate is joggled, that is, the overlapping plate is bent so that the bottoms of the adjacent

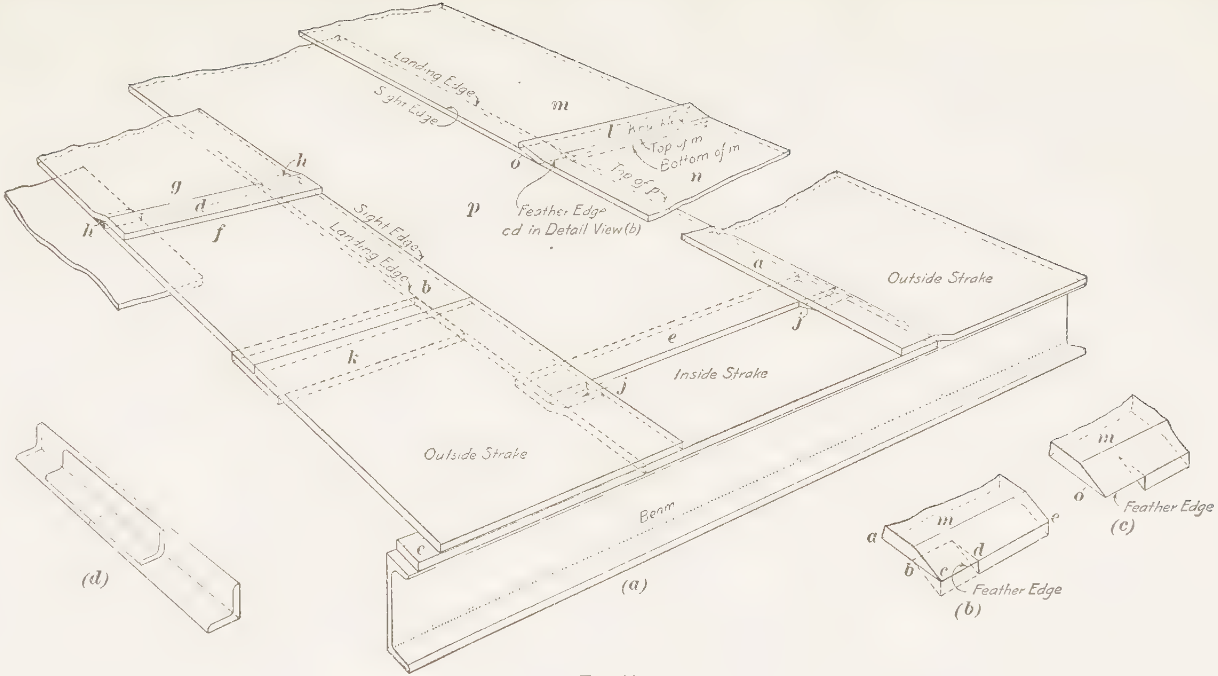

Landing Edge
Sight Edge
m
l
Top of m
Bottom of m
Top of p
n
o
p
Feather Edge
cd in Detail View (b)
h
g
d
f
Sight Edge
Landing Edge
b
a
Outside Strake
j
e
k
Inside Strake
Outside Strake
Beam
c
(a)
(d)
a
m
e
b
c
d
Feather Edge
(b)
m
o
Feather Edge
(c)

Fig. 30

plates are in the same plane. At seam *b*, the overlapping plate is not joggled, and in the way of the beam—that is, over the beam—strips *c*, having the width of the beam flange and the thickness of the under plate, are fitted over each beam to fill the space between the under, or *in*, plates. The joints at *d* and *e* are joggled butt laps. At the sides of the butts are tapered liners, or fillers, shown at *h* and *j*; in joints *d* and *e* these fill up the opening that would otherwise be left between the end of the plate *f* and the point where plate *g* leaves the lower level of plate *f* and passes over the end of plate *f*. These fillers are as long as the edge lap is wide and are held in place by the edge-lap rivets. At *k* is shown a butt strap placed underneath the joint.

61. At *l* is a **scarfed lap.** In this form of joint the lap of plate *n* is *set*, or bent, upwards and that of plate *m* sets downwards so that when the parts of the plates back of the laps are in line, the laps touch each other for their full width.

In order to avoid the bulge in the seam at *o* that would result from such a joint, at that point there is cut out of the under side of plate *m* the wedge-shaped piece shown dotted in view (*b*), where *c d* is the width of the edge lap. When the dotted part is cut out, the part *d e* of plate *m* can project below and to the right of plate *p*, while the part *c d*, which is a feather edge, will be in the position indicated by the straight line *a b c* in view (*b*) and will lie flat on plate *p*. There will then be need of no filler such as was used in joints *d* and *e*. View (*c*) clearly shows the form and position of plate *m* after *c d* has been cut out and the plate has been set, or bent.

62. When plates have lapped edges, the edge that is seen on the outside is called the **sight edge,** and the edge that is covered by the lap is the **landing edge.** The sight edge is on the outside of the shell, on the top of decks and of inner bottoms, and on the opposite side from the stiffeners on bulkheads. The application of these terms is shown in view (*a*). The line *l* at which the plate begins to bend is called the *knuckle*. Of course, all the different joints shown in view (*a*) would not occur on one deck so near together as here shown.

In view (d) is shown an *angle butt strap,* the strap fitting snugly into the bosoms of the connected angles.

63. Straps, Laps, and Rivets.—Tables I, II, and III and their accompanying notes are from Lloyd's Rules and show the requirements for riveted joints under various conditions.

Instructions or schedules showing rivet spacings and sizes are often given on drawings to enable the templet maker or patternmaker to determine the location of rivets on the templets. In some shipyards these rivets are nearly all located on

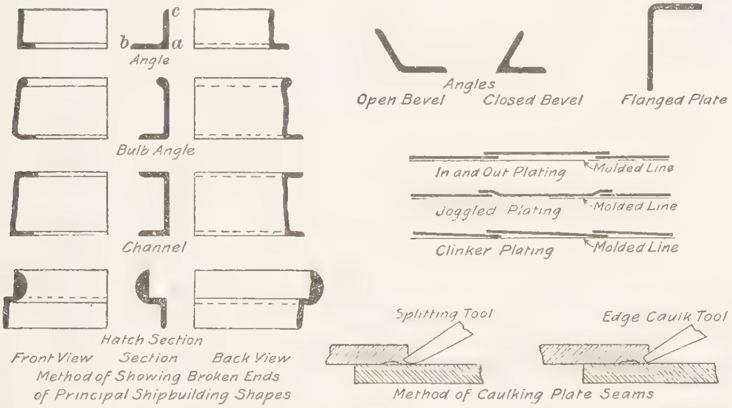


Fig. 31

structural drawings prepared in the drafting room and the templet makers merely mark them on the templet.

64. Shapes and Angles.—In designating the size of angles, three dimensions are given—the length from heel to toe of each leg, as from a to b and from a to c in the angle shown in Fig. 31, and the thickness of the legs, as a $3\frac{1}{2}'' \times 3\frac{1}{2}'' \times .50''$ angle. Different styles of plating are also shown in Fig. 31, as well as various shapes and angles and methods of caulking joints.

65. For the same nominal-sized angle, as for instance $3\frac{1}{2}'' \times 3\frac{1}{2}''$, there is one thickness that agrees exactly with the nominal dimensions, but as the rolls are spread and the thick-

TABLE I

DIAMETERS AND SPACING OF RIVETS AND BREADTHS OF BUTT STRAPS, BUTT LAPS, AND EDGE LAPS

Thickness of plates, in inches	.22 and not Exceeding .34	Above .34 and not Exceeding .48	Above .48 and not Exceeding .66	Above .66 and not Exceeding .88	Above .88 and not Exceeding 1.14	Above 1.14 to 1.20
Diameter of rivets, in inches	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$
Breadth of quadruple-riveted butt straps, in inches			22	25	$28\frac{1}{4}$	$31\frac{1}{2}$
Breadth of treble-riveted butt straps, in inches		$14\frac{1}{4}$	$16\frac{3}{4}$	19	$21\frac{1}{2}$	24
Breadth of double-riveted butt straps, in inches	8	$9\frac{3}{4}$	$11\frac{1}{4}$			
Breadth of single-riveted butt straps, in inches	$4\frac{1}{2}$	$5\frac{1}{4}$				
Breadth of quadruple-riveted butt laps, in inches			12	14	16	18
Breadth of treble-riveted butt laps, in inches		$7\frac{1}{2}$	9	$10\frac{1}{2}$	12	$13\frac{1}{2}$
Breadth of double-riveted butt laps, in inches	$4\frac{1}{4}$	5	6			
Breadth of single-riveted butt laps, in inches	$2\frac{1}{2}$	3				
Breadth of treble-riveted edge laps, in inches				$8\frac{1}{2}$	$9\frac{1}{2}$	$10\frac{1}{2}$
Breadth of double-riveted edge laps, in inches	$3\frac{3}{4}$	$4\frac{1}{2}$	$5\frac{1}{4}$	6	$6\frac{3}{4}$	$7\frac{1}{2}$
Breadth of single-riveted edge laps, in inches	$2\frac{1}{4}$	$2\frac{1}{2}$	3			
Maximum Spac'g from Center to Center: $3\frac{1}{2}$ diam. center to center — In *butts of outside plating, and all beam stringer plates (except quadruple-riveted butt laps)	$2\frac{1}{4}$	$2\frac{5}{8}$	$3\frac{1}{8}$	$3\frac{1}{2}$	4	$4\frac{3}{8}$
Maximum Spac'g from Center to Center: 4 diam. center to center — In edges of outside plating (forward and aft), quadruple-riveted butt laps and double butt straps; butts of deck plating, butts of margin plates, girders, tie-plates, and floor plates; also butts and edges of inner-bottom plating	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5

Maximum Spacing from Center to Center	$4\frac{1}{2}$ diam. center to center	In gunwale angle bars, margin plate angles, quintuple-riveted butt laps, edges and butts of bulkhead plating, angles connecting side stringers to web frames and edges of deck plating	$2\frac{3}{4}$	$3\frac{3}{8}$	4	$4\frac{1}{2}$		
	5 diam. center to center	In flat keel angles, vertical angles connecting floors and center girder; bulkhead frames where caulked; butts and edges of mast plates, floors, and cross-ties in after peak	$3\frac{1}{8}$	$3\frac{3}{4}$	$4\frac{3}{8}$	5	$5\frac{5}{8}$	$6\frac{1}{4}$
	6 diam. center to center	In deck plating to beams where single flange beams are fitted at alternate frames	$3\frac{3}{4}$	$4\frac{1}{2}$	$5\frac{1}{4}$			
	7 diam. center to center	In †frames, reversed frames, floors, keelsons, beam angles, deck and hold stringer angles, face angles on web frames and side stringers, bulkhead stiffeners, longitudinal angles on continuous girders, vertical angles connecting floors and side girders, and deck plating to beams except where single-flange beams are fitted at alternate frames	$4\frac{1}{2}$	$5\frac{1}{4}$	$6\frac{1}{4}$	7		

*In butts connected by single butt straps, alternate rivets may be omitted in the back row of treble riveting when the longitudinal number is 16,000 and under; when above this number, the rivets in the back row are not to be more than 5 to $5\frac{1}{4}$ diameters apart from center to center. All overlapped butts are to have complete rows of rivets.

†The rivets attaching the outside plating to the frames are to be spaced not more than 6 diameters apart from center to center where the depth of framing is above 11 inches, and throughout the vessel where the rule frame spacing is above 26 inches. Where the framing consists of channel bars with reversed frames, the rivets attaching the outside plating to the frames are to be spaced not more than $5\frac{1}{2}$ diameters apart from center to center.

Where the framing is in accordance with the requirements of Table 2, the rivets attaching the reversed frames to the frames are to be spaced the same as the rivets through the frames and outside plating.

In deep water-ballast tanks and in fore and after peak tanks, the rivets through the frames and outside plating are to be spaced not more than $5\frac{1}{2}$ diameters apart from center to center.

Before the three-fifths lengths of a steamer having a tonnage coefficient of .76 or having a full form at the fore part, the rivets in the frames and plating forming the flat of the bottom are to be spaced not more than $5\frac{1}{2}$ diameters apart from center to center.

TABLE II
BUTT STRAPS

Thickness of Plates Inches	Thickness of Butt Straps			Thickness of Plates Inches	Thickness of Butt Straps		
	Single Inches	Double			Single Inches	Double	
		Strap Which is Countersunk for Rivets Inches	Strap on Opposite Side of Plate Inches			Strap Which is Countersunk for Rivets Inches	Strap on Opposite Side of Plate Inches
.22	.22			.72	.90	.52	.44
.24	.24			.74	.94	.54	.44
.26	.26			.76	.96	.56	.46
.28	.28			.78	.98	.58	.48
.30	.30			.80	1.00	.58	.50
.32	.34			.82	1.04	.60	.50
.34	.38			.84	1.06	.60	.52
.36	.40			.86	1.08	.62	.52
.38	.44			.88	1.10	.62	.54
.40	.48			.90	1.12	.64	.56
.42	.52			.92	1.16	.64	.58
.44	.54	.34	.28	.94	1.18	.66	.60
.46	.58	.36	.28	.96	1.20	.66	.62
.48	.60	.38	.30	.98	1.22	.68	.62
.50	.62	.40	.30	1.00	1.24	.68	.64
.52	.64	.40	.32	1.02	1.28	.70	.64
.54	.68	.42	.32	1.04	1.30	.70	.66
.56	.70	.42	.34	1.06	1.32	.72	.66
.58	.74	.44	.34	1.08	1.34	.72	.68
.60	.76	.44	.36	1.10	1.38	.74	.68
.62	.78	.46	.36	1.12	1.40	.74	.70
.64	.80	.46	.38	1.14	1.44	.76	.70
.66	.82	.48	.40	1.16	1.46	.76	.72
.68	.86	.48	.42	1.18	1.48	.78	.72
.70	.88	.50	.42	1.20	1.50	.78	.74

ness of metal is increased or decreased as indicated in Fig. 32, the actual length of the leg varies, but the angle is called by the nominal size instead of the actual.

Angles are rolled with equal legs or unequal legs; in general, those with equal legs are used for connections and those with unequal legs for stiffeners with the shorter leg against the surface that is to be stiffened.

Bulb-angle sizes are indicated in the same manner as those of other angles and their thickness is varied in a similar manner.

66. Channels are designated by giving the depth of the web, the nominal length of the flanges, which are equal, and the thickness of the web, as 8″×3½″×3½″×.50″. As the

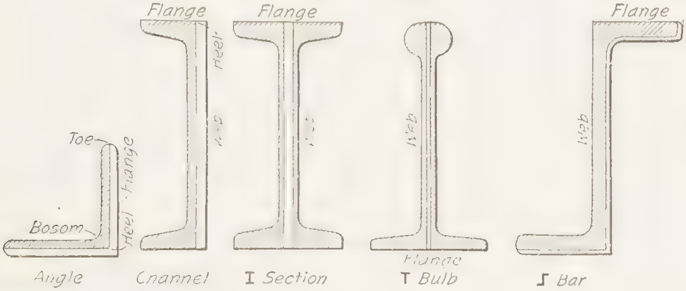


Fig. 32

thickness is increased the length of the flanges increases but the depth of the web remains constant. In shipbuilding channels, the thickness of the flange is nearly constant the full length and is greater than that of the web, whereas in structural channels, such as those used in bridges and buildings, the flanges are much thicker near the web than near the toe.

67. Plates and shapes are also designated by weight. A steel plate 1 inch thick and of 1 square foot area weighs 40.8 pounds. Generally, though, plate weights are given in even pounds or half pounds.

Plates designated as 40-pound plate, 20-pound plate, 10-pound plate, and 5-pound plate are, respectively, nearly 1 inch, ½ inch, ¼ inch, and ⅛ inch thick, the weight being that

TABLE III

RIVETING OF BUTTS AND EDGES

	Thickness of Plates											
	.22 and Not Exceeding .36	Above .36 and Not Exceeding .38	Above .38 and Not Exceeding .42	Above .42 and Not Exceeding .48	Above .48 and Not Exceeding .54	Above .54 and Not Exceeding .60	Above .60 and Not Exceeding .68	Above .68 and Not Exceeding .76	Above .76 and Not Exceeding .84	Above .84 and Not Exceeding .94	Above .94 and Not Exceeding 1.04	Above 1.04 and Not Exceeding 1.20
a	Double	Double	Treble	Treble	Treble	Treble	Quadruple	Quadruple	Quadruple	Double straps treble riveted	Double straps treble riveted	Double straps treble riveted
b	Double	Treble	Treble	Treble	Treble	Treble	Treble	Quadruple	Quadruple	Quadruple	Quadruple	Double straps treble riveted
c	Double	Double	Double	Treble	Treble	Treble	Treble	Treble	Quadruple	Quadruple	Quadruple	Quadruple
d	Double	Double	Double	Treble	Treble	Treble	Treble	Quadruple	Quadruple	Quadruple	Quadruple	
e	Double	Double	Double	Double	Treble	Treble	Treble	Quadruple	Quadruple	Quadruple	Quadruple	
f	Single	Single	Single	Double	Double	Treble	Treble	Quadruple	Quadruple			
g	Single	Double	Double	Double	Double	Double	Double	Double	Double	Double	Double	
h	Single	Single	Single	Single	Double	Double	Double	Double	Double	Treble	Treble	
i	Single	Single	Single	Single	Single	Double	Double	Double	Double			
k	Single	Single	Single	Double	Double	Double	Double	Double	Double			
l	Single	Single	Single	Single	Double	Double	Double	Double				

NOTES TO TABLE III

The requirements as to attachments are to be regulated by the thicker of the plates connected.

The edge attachments all fore and aft of outside plating and middle-line strake of inner-bottom plating are to be regulated by the thickness of the plating amidships.

Where the breadth of any strake of outside plating exceeds the limits given in the following table, additional riveting is to be provided at the butts in excess of that required by the thickness of the plates.

Depth (D) of Vessel Feet	Maximum Breadth of Strake for Rule Riveting Inches
Not exceeding 20........................	54
Above 20 and not exceeding 24...........	60
Above 24 and not exceeding 28...........	66
Above 28	72

Butts of side plating of "short" deck erections should not be less than double-riveted.

As an alternative arrangement to the treble-riveted double butt straps required by the above table, quintuple-riveted overlapped butts may be adopted, except for strakes which are doubled.

a. Butts of sheerstrake, strake below and stringer plates, of the uppermost deck, whether upper, awning, or shelter deck or "long" bridge, for half the vessel's length amidships.

Where the sheerstrake is doubled, single butt straps treble-riveted are to be fitted to the butts of the sheerstrake and doubling plate, of the same thickness as the plates connected.

Butts of outside plating from keel to upper turn of bilge for half the vessel's length amidships.

Butts of boss plates.

Butts of center girder plates in double bottoms.

Butts of floor plates and web frame plates.

b. Butts of flat keel plates for half the vessel's length amidships.

Where the flat keel plates are doubled, single butt straps treble-riveted are to be fitted to the butts of the keel plate and doubling plate, of the same thickness as the plates connected.

c. Butts of flat keel plates at ends of vessel.

d. Butts of outside plating from upper turn of bilge to strake below sheerstrake.

Butts of outside plating from keel to upper turn of bilge at ends of vessel.

Butts of sheerstrake, strake below and stringer plates of upper and awning or shelter decks at ends of vessel.

Butts of beam stringer plates of second decks and decks or tiers of beams below.

Butts of tie plates.

Butts of margin plates and middle-line strake of double bottoms for half the vessel's length amidships.

e. Butts of deck plates for half the vessel's length amidships.

Butts of inner-bottom plating for half the vessel's length amidships.

Butts of the side girders in double bottoms.

Butts of margin plates and middle-line strake of double bottoms at ends of vessel.

f. Butts of deck plates at ends of vessel.

Butts of inner-bottom plating at ends of double bottoms.

g. Edges of outside plating from keel to turn of bilge.

Joining seams of stringer plates where the stringer is fitted in two breadths.

h. Edges of outside plating from upper turn of bilge to strake below sheerstrake.

The edges of sheerstrake are to be double-riveted except where the thickness of the side plating is above .84 of an inch, when they are to be treble-riveted.

In vessels exceeding 480 feet in length and where the thickness of the side plating is not more than .84 inch, the landing edges are to be treble-riveted for one-fourth of the vessel's length in the fore and after bodies for a depth of one-third the depth of the vessel, the actual position of this treble riveting to depend upon the arrangement of shell plating and the special design of the vessel, or other equivalent strengthening to be afforded. Vessels of from 450 feet to 480 feet in length are to be additionally riveted at the before-mentioned parts proportionately to their length, or to have other equivalent strengthening. Each case requiring this additional riveting of the seams is to be submitted for the approval of the committee. Where the thickness of the side plating is above .84 inch, the edges are to be treble-riveted for four-fifths of the vessel's length amidships.

i. Edges of deck plates.

k. Edges of middle-line strake of inner-bottom plating.

l. Edges of inner-bottom plating except middle-line strake.

per square foot. Angles, channels, bulb angles, etc., may be also designated as so many pounds per linear foot; thus, a $3\frac{1}{2}'' \times 3\frac{1}{2}'' \times 8.5$-pound angle has the dimensions given and weighs 8.5 pounds per linear foot.

68. Marks and Numbers on Parts.—In making drawings in shipyard offices, it is usual to give every piece of structural work a distinguishing mark so that when the various pieces come from the different parts of the shop to be assembled or bolted together the workman will be able to pick out the right ones, or, if they are to be sent to the ship singly and stacked in piles, the part needed can be quickly recognized. When several pieces are identical, they may each have the same piece mark. As ships are given a contract number, or *hull number,* by the builders, the piece mark should contain the hull number, a mark designating the part of the ship, and a part mark. The same structure should have the same distinguishing mark in all ships in any one yard. By structure is meant deck, shell, bulkhead, frame, etc. The marks employed are letters and numbers. The systems of marking are different in different yards.

The size of the plates used on the shell, decks, bulkheads, etc. depends on the size of the ship and on the facilities for handling and the tools for working that the builder has at hand. Generally speaking, the larger the plate that can be conveniently handled the better. Shell plates usually are from 18 feet to 30 feet long, depending on the size of the ship, and the width varies accordingly but should not be so great that the punches available cannot reach the middle holes.

69. Water-Tight Joints.—In water-tight work, rivets are spaced closer than in non-water-tight work. Water-tight structures are *caulked,* that is, the metal of one plate is forced up against the metal of the other by means of caulking tools resembling cold chisels and driven by hand hammers or pneumatic hammers. In Fig. 31 is shown the method of securing tightness in a seam or at the edges of butt straps. The splitting tool is first used in the manner shown to cut a groove in the upper plate, then with the edge-caulking tool the metal

near the edge of the upper plate is forced back into closer contact with the lower plate and the joint is made water-tight. Similar methods are used in caulking flush joints.

70. When a channel, bulb angle, or angle passes through a plate and water-tightness is required, it is necessary to *staple* about the part passing through. This consists in fitting angle collars around them and caulking as described. Fig. 33 shows the stapling about a channel frame at the ship's side. In (*a*) and (*c*) dotted lines indicate the cut in the deck plate through which the frame passes. In (*a*) and (*b*) is shown the construction (front and back) when there is no stringer angle along the face of the frame. Angle *a* against the shell is bent around the inside of the channel frame and a piece is welded in at *b* to cover entirely the cut in the plate. Angle *c* shown in (*a*) and (*b*) is bent at two places at the back of the channel, as shown in (*a*), and is riveted to angle *a*. The edges of *a* and *c* are caulked.

In view (*c*) there is a continuous stringer angle *e* running along the face of the frames. The *stapling* is made of a channel *d* of the same width as the frame and having its ends bent up or boxed at the frame.

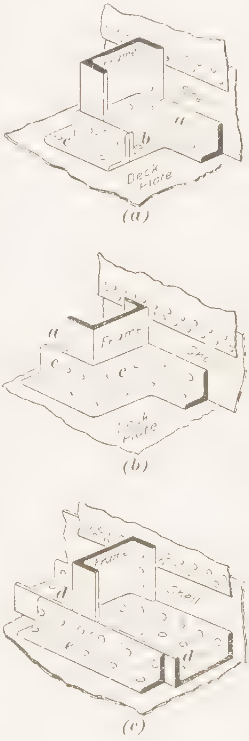


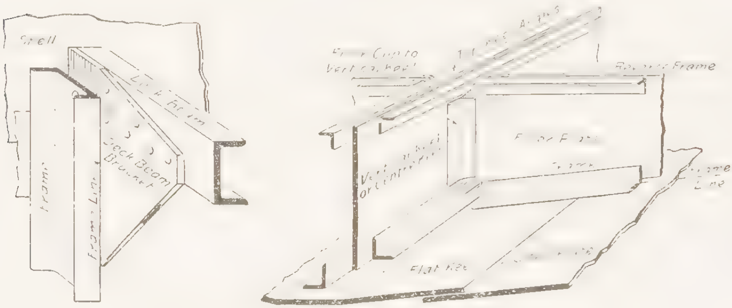
FIG. 33

It will be noted in (*a*) and (*c*) that *a* and *d* are joggled over the flanges of the frame.

Sometimes it is impossible or impracticable to secure metal-to-metal water-tightness, and stopwaters—pieces of canvas soaked in red lead—are inserted between the two metal pieces when assembling; these are compressed when the joint is riveted.

71. Frames.—It was shown in Fig. 6 that the frames are arranged at regular intervals for the full length of the ship. The angles or channels of which the frames are made toe toward the middle of the length of the ship, those forward of amidships toeing aft and those aft of amidships toeing forwards. For example, the frame shown in Fig. 34 (*a*) is one that is forward of amidships and on the port side, as the toes of the flanges of the channel point toward amidships.

The web of the frame is perpendicular to the center line of the ship and the flange is beveled to take the shape of the side, or shell. Near the ends of the ship, where the shell tapers sharply toward the center line, there may be considerable bevel to the frames; but, by placing them in the way



(*a*) (*b*)

FIG. 34

described, the bevel of the inner side of the flange is always open and easily got at for riveting. If the frames toed in the opposite direction the bevels at such places would be closed so much that proper riveting would be difficult.

72. The **frame line** is the line of intersection of the back of the frame—that is, the heel of the angle or channel forming the frame—with the shell. The *frame spacing,* or the distance between frames, is measured from frame line to frame line.

In Fig. 34 (*b*) it will be seen that coincident with the frame line are the front of the floor plate, the heel of the reverse frame, and the heel of the clip connecting the floor and the vertical keel. In view (*a*) the frame line is marked at the inboard heel of the channel frame but of course the outer heel

is in the same plane. Note that the heel of the channel deck beam is separated from the frame line by the thickness of the beam bracket. The deck stringer and plating are not shown.

In (*b*) it will be noted that the floor plate does not extend quite to the heel of the frame. The inner-bottom plating which goes on top of the reverse frame is not shown.

In vessels with an inner bottom the frames are cut at the margin or edge of the inner bottom but the heels of the frames in and out of the inner bottom are in the same transverse plane.

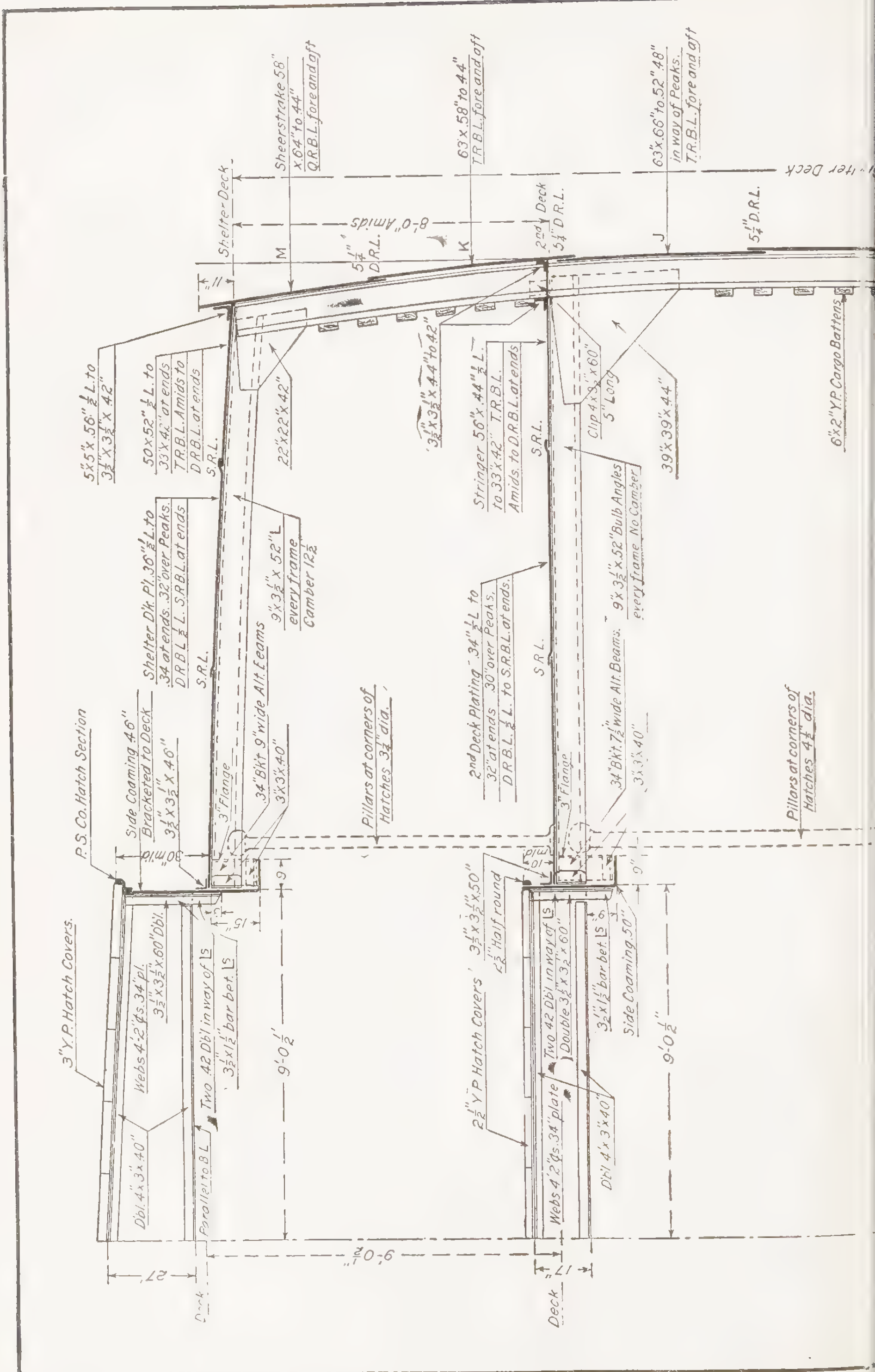
ABBREVIATIONS USED ON DRAWINGS

73. On account of the many varying details which on the scale of the ordinary ship drawing cannot be shown plainly, ship drawings require that the various parts be accurately lettered so that there may be no doubt of the construction, dimensions, or weight of material to be used. When such lettering would be crowded on a drawing, the following abbreviations may be used.

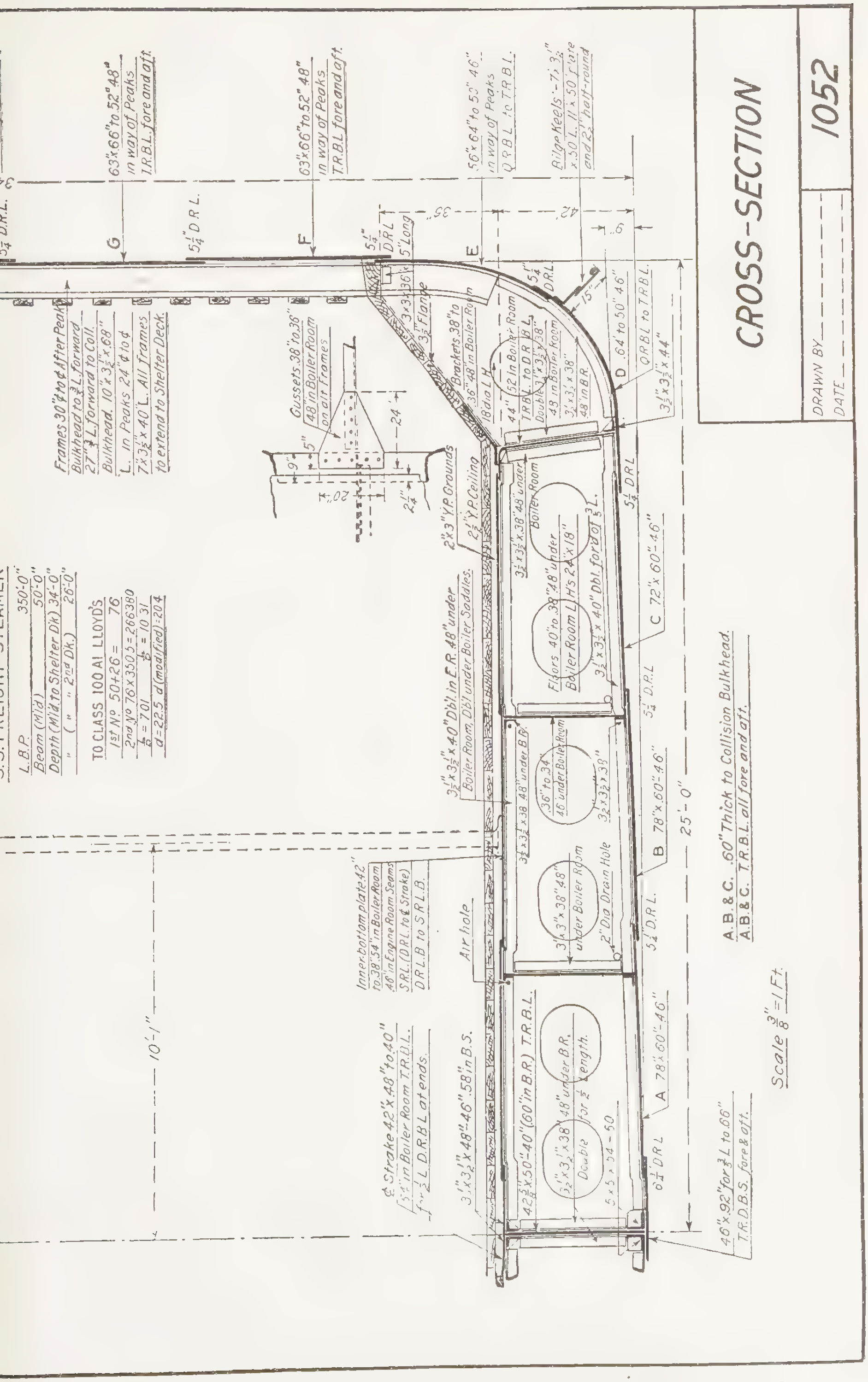
Some Abbreviations Used on Drawings

Alt.	Alternate
Amids.	Amidships
A. P.	After perpendicular
∟	Angle
∟ or B. A.	Bulb angle
B. R.	Boiler room
B. S.	Boiler space
Bkt.	Bracket
B. L.	Base line
Blkd.	Bulkhead
C. B. P.	Center between perpendiculars
℄ or C. L.	Center line
⊓	Channel
Coll. Blk'd	Collision bulkhead (first bulkhead aft of stem)
C't's'k	Countersunk
D. or Dia.	Diameter
D. R. B. L.	Double-riveted butt lap

D. R. D. B. S.	Double-riveted double butt strap
D. R. L.	Double-riveted edge lap
D. R. S. B. S.	Double-riveted single butt strap
Dbl.	Double
Dk.	Deck
E. R.	Engine room
F. P.	Forward perpendicular
Fl.	Flange or floor (meaning will be evident)
Fr.	Frame
Galv.	Galvanized
H. R.	Half-round
$\frac{1}{2}$ L.	Half length
L. H.	Lightening hole
Mld.	Molded
O. T. B.	Oil-tight bulkhead
O. T. F.	Oil-tight floor
O. T. M.	Oil-tight manhole
Pl.	Plate
℔	Pounds
Q. R. B. L.	Quadruple-riveted butt lap
Q. R. D. B. S.	Quadruple-riveted double butt strap
Q. R. S. B. S.	Quadruple-riveted single butt strap
R., r., or Rad.	Radius
Rev.	Reverse
S. R. B. L.	Single-riveted butt lap
S. R. L.	Single-riveted edge lap
Str.	Stringer
T. R. B. L.	Treble-riveted butt lap
T. R. D. B. S.	Treble-riveted double butt strap
T. R. L.	Treble-riveted edge lap
T. R. S. B. S.	Treble-riveted single butt strap
$\frac{3}{5}$ L.	Three-fifths length
W. I. P.	Wrought-iron pipe
W. T.	Water-tight
W. T. B.	Water-tight bulkhead
W. T. F.	Water-tight floor
W. T. M.	Water-tight manhole
Y. P.	Yellow pine



Shelter-Deck
Sheerstrake .58"
x .64" to .44"
Q.R.B.L. fore and aft
63 x .58" to .44"
T.R.B.L. fore and aft
63" x .66" to .52" .48"
in way of Peaks.
T.R.B.L. fore and aft
8'-0" Amids
2nd Deck
5¼" D.R.L.
5"x5" x .56" ½ L. to
3½" x 3½" x .42"
50 x .52" ½ L. to
.33" x .42" at ends
T.R.B.L. Amids to
D.R.B.L. at ends
S.R.L.
22" x 22" x .42"
Stringer .56" x .44" ½ L.
to .33" x .42" T.R.B.L.
Amids. to D.R.B.L. at ends
S.R.L.
Clip 4 x 3½ x .60"
5" Long
39" x 39" x .44"
6" x 2" Y.P. Cargo Battens
Shelter Dk. Pl. .36" ½ L. to
.34 at ends .32" over Peaks.
D.R.B.L. ½ L. S.R.B.L. at ends
S.R.L.
9" x 3½" x .52" L
every frame
Camber 12½
2nd Deck Plating .34" ½ L. to
.32" at ends .30" over Peaks.
D.R.B.L. ½ L. to S.R.B.L. at ends.
9" x 3½" x .52 Bulb Angles
every frame No Camber
P.S. Co. Hatch Section
Side Coaming .46"
Bracketed to Deck
3½" x 3½" x .46"
30" m/d
3" Flange
34" B'k't 9" wide Alt. Beams
3" x 3" x .40"
Pillars at corners of
Hatches 3¼" dia.
34" B'k't 7½" wide Alt. Beams.
3" x 3" x .40"
Pillars at corners of
Hatches 4½" dia.
3" Y.P. Hatch Covers.
Webs 4'-2" d's .34" pl.
3½" x 3½" x .60" Dbl.
Two .42 Dbl in way of Ls
3½" x 1½" bar bet. Ls
Dbl. 4" x 3" x .40"
Parallel to B.L.
9'-0½"
9'-0½"
27"
Deck
3½" x 3½" x .50"
1½" Half round
2½" Y.P. Hatch Covers
Two .42 Dbl in way of Ls
Double 3½" x 3½" x .60"
3½" x 1½" bar bet. Ls
Side Coaming .50"
Webs 4'2" d's .34" plate
Dbl 4" x 3" x .40"
17"
Deck



NAME, CLASS LETTERS, AND NUMBER

SHIP DRAFTING
(PART 2)

DRAWING PLATES—(Continued)

PLATE 1052: TITLE, CROSS-SECTION

1. The plates to be drawn in connection with this and following Sections are to be of the same size and general arrangement as those already drawn for the Sections on *Geometrical Drawing* and *Mechanical Drawing,* and in general, the same instructions as to lettering, putting on the student's class letters and number, sending in the plates, etc., will apply. On some of the plates, however, in connection with the title, the place occupied on the Mechanical Drawing plates by the material list is taken by the riveting instructions or a list of details, which are arranged in a similar manner.

Plate 1052 represents a cross-section of a ship. Fig. 1 is a view of a ship that has been cut in the middle and the ends pulled apart. This view shows in perspective very nearly what plate 1052 shows in a drawing, though the ship in the picture has more decks than the one in the drawing. Some of the principal parts in the picture are lettered, and a comparison of this view with Fig. 6 in *Ship Drafting,* Part 1, will make plain the names of many others.

Before taking up the drawing of Plate 1052, reference must be made to the use that is made of the body plan and the offsets taken from it. This plan was shown in Plate 1051 and described in *Ship Drafting,* Part 1.

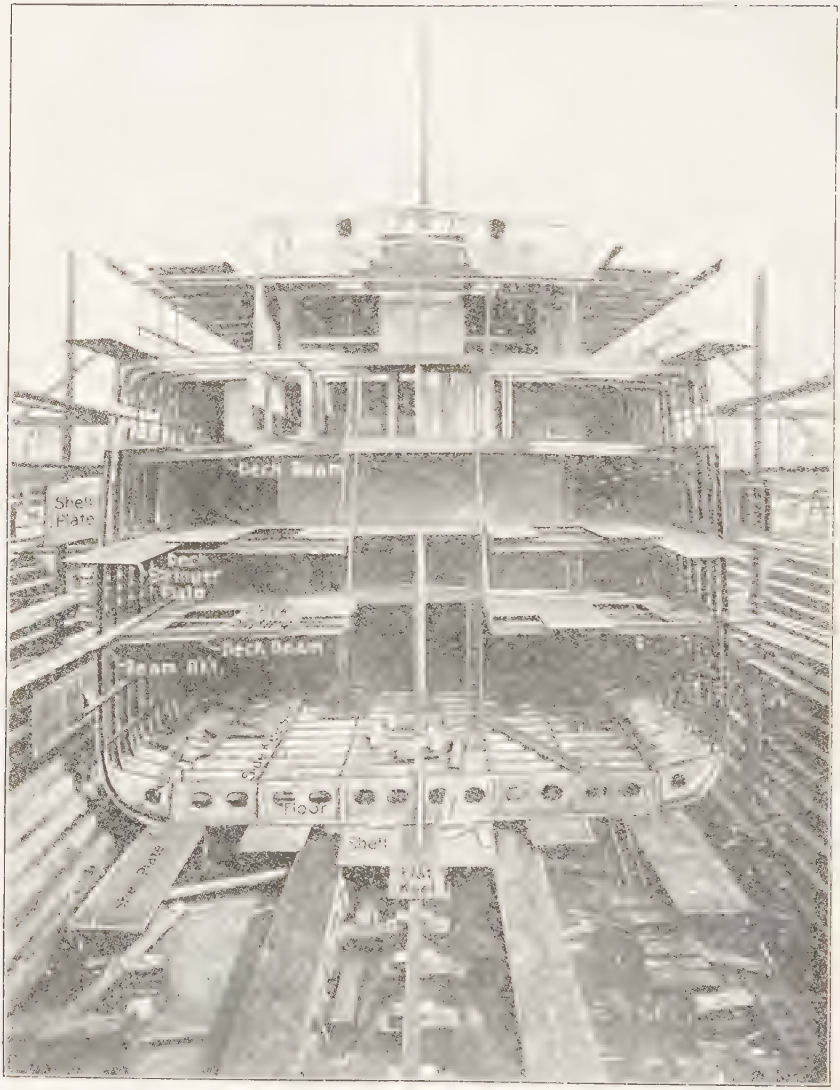


FIG. 1

BODY PLAN AND OFFSETS

2. As shown in Plate 1051, the *lines* define the shape of the ship; therefore a careful record of them must be available for making the drawings of the shell, decks, bulkhead framing, inner bottom, and other parts whose shapes depend on them. This record consists of two body plans, one of the forward body and one of the after body, made to a scale of $\frac{1}{2}$, $\frac{3}{4}$, or 1 inch to the foot, and drawn on glass or on marble slabs. Such drawings will not expand and contract with the weather, and when inked will stand a fair amount of usage.

Structural steel for the hull is ordered partly from these body plans, partly from half models made of wood to scale of $\frac{1}{4}$ inch=1 foot, and partly from detail drawings.

3. Besides these body plans, there is the most permanent and important record of all—the offsets. These are taken from the large body plans, and give the horizontal distance from the center line to the molded frame line on each of the water lines, which are usually drawn 2 or 3 feet apart and closer when necessary. The offsets also give the height of each buttock above the base line at every frame, the heights of the decks from the base line, the location of the edges of the shell plates, the location of side keeisons and stringers by half widths from the center line or by the heights above the base line, and all other dimensions of the lines, such that the entire molded form of the vessel and the locations of all members of the structure are definitely fixed. Offsets are given in feet, inches, and eighths of an inch, 24–10–3 reading 24 feet $10\frac{3}{8}$ inches, 23–10–0, reading 23 feet 10 inches, and 0–7–4 reading $7\frac{1}{2}$ inches.

4. The body plan is also laid down to full size on the floor of the mold loft. This loft is so called from its being the place where molds, or patterns, are made. Formerly the waterlines, sheer plan, and body plan were laid down there and the fairing of the lines was done; but by the use of the glass or marble tables this can be more economically done in the draw-

ing room, and now all that is laid down in the loft is the body plan complete with projections of shell sight edges, projections of decks, projections of the floors, and of the longitudinals, or keelsons.

All plates, angles, and other shapes entering into the construction of the vessel are laid out from patterns or templets made in the mold loft from the full-size body plans and the detail drawings. These templets are made of very heavy paper or of wood about $\frac{3}{8}$ of an inch thick, the material employed depending on the number of times they are to be used. The templet of any shape or plate is a full-size pattern showing in detail the location and sizes of all rivet holes and cut-outs, outlines of edges, flanging, or rolling lines, and gives the necessary information for marking out the plate or part. The templet is secured to the plate or shape and the form is transferred or marked upon it, all rivet holes being center-punched through.

DESCRIPTION OF PLATE

5. The cross-section drawing, such as Plate 1052, is a transverse half section through the fullest section of a vessel. In building a ship, it is the first structural drawing made, as it shows the general construction of the ship and the size of all the principal parts.

Usually this drawing shows the deck plating running up to a line of hatches. Ordinarily in a ship the machinery space is amidships and the cargo hatches are toward the ends, but the cross-section is drawn in this conventional way to show best the general construction of the vessel. From this and the general arrangement drawings, the drawings of the structural parts of a ship are made.

In actual practice, the contour, or molded shape, is drawn from the offsets measured on the body plan, as explained. The accompanying table of Offsets for Midship Section gives all the offsets that are necessary for constructing the cross-section in this case. Fig. 2 will help to make plain the location of the various parts and measurements referred to in this description.

6. To draw the plate, first draw the vertical center line of the ship, as at *a b*, Fig. 2, 1¼ inches from the left-hand border line of the long side of the plate; then draw the molded base line perpendicular to the center line and 2 inches above the bottom border.

The plate is to be drawn to a scale of ⅜ inch=1 foot, and from now on all measurements will be given in dimensions of the vessel.

At a distance of 25 feet to the right of the center line, draw the molded side line *c d* so that it extends about 35 feet above

OFFSETS FOR MIDSHIP SECTION

WATER LINES	HALF WIDTHS
1′	22–3–4
2′	23–9–0
3′	24–5–2
4′	24–9–6
5′	24–11–5
6′–22′	25–0–0
24′	24–11–4
26′	24–10–4
28′	24–8–6
30′	24–6–0
32′	24–3–0
34′	23–11–4
Gunwale	23–9–6
BUTTOCKS	HEIGHTS ABOVE MOLDED BASE LINE
20′	0–7–2
22′	0–10–6
24′	2–3–3

the base line. On this, draw lightly the water-lines shown in Fig. 2 and listed in the Table of Offsets, and on them tick off the corresponding half widths taken from the offsets. Draw also buttocks, as *c f*, at the distances from the center given in the table, and on each buttock mark off the height above the base line as given; these points of measurement are indicated by dots in Fig. 2. Next, on each water-line from *1′* to *6′*,

inclusive, lay off the half widths from the Table of Offsets and tick off these points, as *g*, *h*, *i*. On the side line *c d*, lay off the 9-inch dead rise as at *j*, and on the base line lay off the

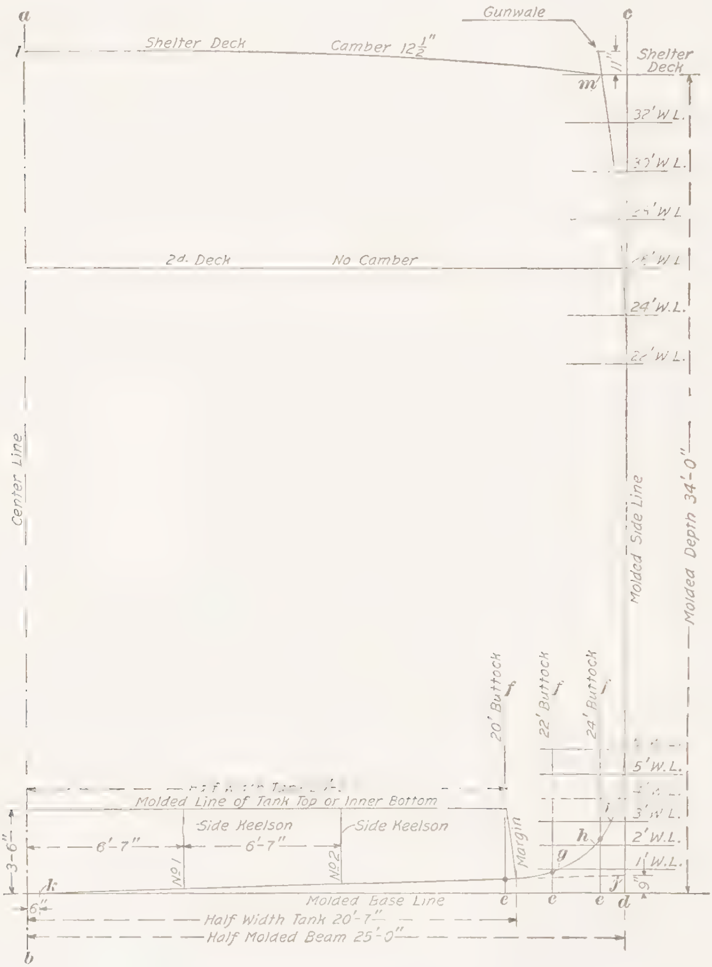


FIG. 2

half siding at *k* 6 inches from the center line; the line connecting the points *k* and *j* is called the *dead-rise line*. With the ship curve and irregular curves, draw the line through the points that have been marked on the water-lines and buttocks.

These lines will come fair and will be tangent to the molded side line *c d* and the dead-rise line *j k*.

Next, locate the height of the shelter deck, which is 34 feet above the molded base line. The height of the gunwale is 11 inches above the deck line and is to be located by a light line, and on this the position of the gunwale, determined from measurements given in the Table of Offsets, is marked. Then the molded line of the ship from the gunwale to water-line *22′* is drawn through points that have been located on the various water-lines by means of the offsets, and this line becomes tangent to the molded side line at water-line *22′*.

The intersection of the shelter deck and the side of the ship at *m* is at the 34-foot water-line, and the Table of Offsets shows that point to be 23 feet $11\frac{1}{2}$ inches from the center line. Then, as the camber of the deck is given in Fig. 2 as $12\frac{1}{2}$ inches in the half width of the deck, the point *l* where the deck intersects the center line is $34' + 12\frac{1}{2}'' = 35$ feet $\frac{1}{2}$ inch above the base line. Points on the shelter-deck line may be determined by any of the methods that have been given for drawing a camber, and the deck line may be drawn by use of a long ship curve.

7. The second deck, which is 26 feet above the base line and has no camber, is to be drawn next. Finally the molded lines of the tank top, or inner bottom, the side keelsons, and margin are drawn from the dimensions given in Fig. 2. Ordinarily these dimensions would be taken from the Table of Offsets. All lines should be drawn with a sharp chisel pencil point, but not so heavy but what they will erase after the ink lines are drawn.

8. The lines so far drawn constitute the molded contour lines of the drawing, or the lines on which the structure is built. To build up or draw the structure, the keel and the shell plating are first drawn. The strips, or rows, of plating run lengthwise of the structure, and are called strakes.

9. On the drawing plate, the widths of the different strakes are given and also the thicknesses of the plates. Thus, the

keel-plate strake is marked *46″×.92″ for $\frac{3}{5}$ L. to .66″*, which means that the strake is 46 inches wide and that for $\frac{3}{5}$ of the length of the vessel the plate is .92 inch thick and for the remainder it is thinned down to .66 inch, the thinner portions being toward the ends of the ship where the strains are less than in the other part. The reduction in thickness is made at each succeeding plate, each plate being of constant thickness throughout its length. In a similar manner the dimensions given for strake *A* are read 78 inches wide by .60 inch thick with thickness reduced to .46 inch toward the ends. Other members, as angles, channels, etc., likewise vary in thickness and are indicated in like manner. Other dimensions necessary for making the drawing are given on the plate and the meaning of the abbreviations used will be found in the list of abbreviations given in *Ship Drafting,* Part 1.

As an assistance to those unfamiliar with ships, Fig. 3 is given in which the names and locations of the principal parts referred to in this and following plates are plainly indicated. Also, accompanying this Section is a separate *Index to Ship-Drafting Terms,* by reference to which it is possible to turn readily to the place where the meaning of each term is described. This should be referred to in all cases of doubt, as familiarity with the exact meaning of a name or term may make clear what otherwise would be difficult to understand.

10. As shown on the plate, this vessel has joggled frames in the inner bottom; that is, the frames are bent, or joggled, so that while the inside surface of the *in* strakes is on the molded line, the joggle in the frame supports the next, or *out,* strakes outside of the molded line a distance equal to the thickness of the *in* plate. The keel, being an out strake, will therefore be below the molded line. Its width is 46 inches, therefore lay off the extreme edge of the keel plate 23 inches to the right of the center line, and $6\frac{3}{4}$ inches to the left of this point lay off a point that will be the inboard edge of the strake next to the keel plate. This strake is lettered *A* on the drawing plate and succeeding strakes are lettered in regular order. Strake *A,* 78 inches wide, is drawn as a heavy line with its

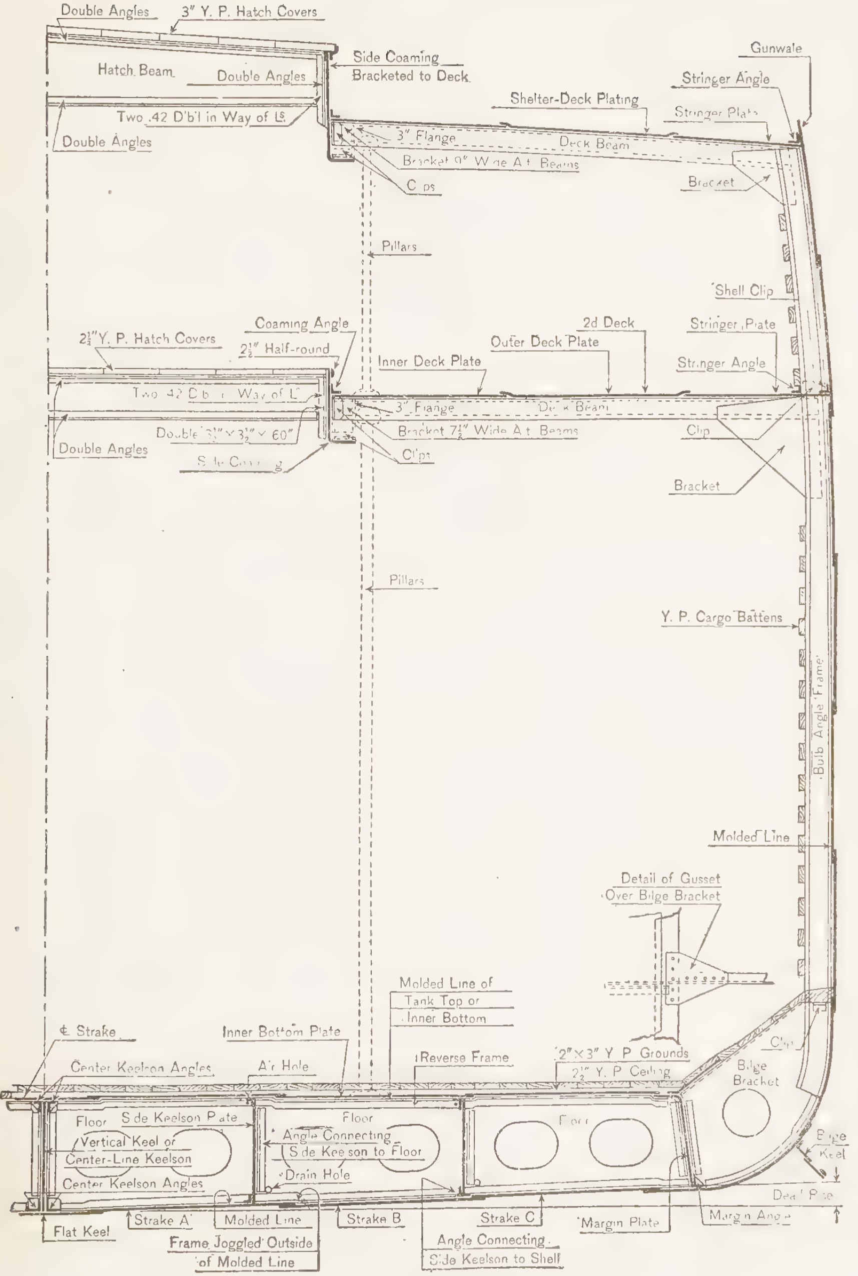
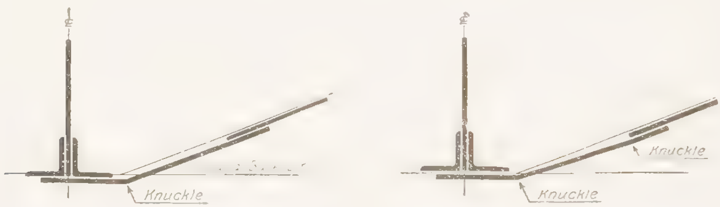

Double Angles
3" Y. P. Hatch Covers
Hatch Beam
Double Angles
Side Coaming
Bracketed to Deck
Gunwale
Stringer Angle
Shelter-Deck Plating
Two .42 D'b'l in Way of Ls
Double Angles
3" Flange
Deck Beam
Bracket
Pillars
Shell Clip
Coaming Angle
2d Deck
Stringer Plate
Outer Deck Plate
Inner Deck Plate
Stringer Angle
Clip
Bracket
Pillars
Y. P. Cargo Battens
Bulb Angle Frame
Molded Line
Detail of Gusset
Over Bilge Bracket
Molded Line of
Tank Top or
Inner Bottom
Strake
Inner Bottom Plate
Center Keelson Angles
Air Hole
Reverse Frame
Floor
Side Keelson Plate
Vertical Keel or
Center-Line Keelson
Center Keelson Angles
Floor
Drain Hole
Bilge Bracket
Bilge Keel
Flat Keel
Strake A
Molded Line
Strake B
Strake C
Margin Plate
Frame Joggled Outside
of Molded Line
Angle Connecting
Side Keelson to Shell

FIG. 3

upper side even with the molded line in the manner shown in Fig. 17 in *Ship Drafting,* Part 1.

11. All plates and shapes that run fore and aft and are cut by the cross-section drawing are shown in heavy lines. The flat plate keel is drawn parallel to the base line as far as the knuckle *k,* Fig. 2, at the dead-rise line, and then parallel to the dead-rise line or strake *A,* and is distant from the knuckle and the dead-rise line by the thickness of strake *A,* as shown in Fig. 4 (*a*). If the keel were made as shown in Fig. 4 (*b*), there would be two knuckles on the plate, and these are not easily made. On the small scale of the cross-section drawing, this bend, or knuckle, in the plate is not plainly seen, but the depth of the center-line keelson shows that such a bend is necessary for, as shown on the drawing plate, the center-line keelson



(*a*) (*b*)

Fig. 4

extends from the molded line of the inner bottom, or tank top, to the keel plate, and, as just stated, the keel plate is outside the molded line of the vessel by the thickness of plate *A,* which is .60 inch. According to Fig. 2, the molded line of the tank top is 42 inches above the molded line of the ship, therefore the keelson plate is 42.60, or $42\frac{5}{8}$, inches deep, as shown on the plate.

12. After drawing the keel plate, locate the inner edge of strake *B,* $5\frac{1}{4}$ inches inboard of the outboard edge of strake *A.* Lay off the width of strake *B,* 78 inches, and locate the inboard edge of strake *C,* the edge lap being $5\frac{1}{4}$ inches. Strake *C* is 72 inches wide, and, being an inside strake, is drawn the same as at *A*; also strake *B* is drawn in a heavy line with its inner surface flush with the outer surfaces of *A* and *C.*

Now locate the gunwale, or upper edge of the top strake *M*, 11 inches above the molded line of the shelter deck, and draw the strake as an *in* strake 58 inches wide. This strake is called the *sheer strake*, since it outlines the sheer of the ship, its upper edge being parallel with the shelter, or upper, deck for the full length of the ship.

13. Above the bilge, the frames are not joggled and the shell plating is on the *in and out* system; therefore in the way of the outer strakes—that is, between them and the frames—liners, or strips, of the width of the frame and the thickness of the adjacent *in* strakes, fill the space between the edges of the adjacent inner strakes and between the frame and the inner surface of the *out* strake, in the manner shown in Fig. 30 in *Ship Drafting*, Part 1. These liners are punched and the rivets attaching the shell to the frame pass through the liners, thus securing them firmly in place. It is not usual to show these liners on drawings.

14. In the same manner as for the bottom strakes, lay out the shell plating down to the lower edge of strake *E*, using the dimensions given on the drawing plate. Having laid off the widths of the seams at the lower edge of *E* and the outer edge of *C*, the last strake *D*, or the *filling-in* strake, is drawn. Its width is not given on the drawing, as its width is frequently taken from the work.

It will be noted that several of these side strakes are of the same width; this is a desirable feature, since one templet will suffice for making a large number of shell plates in these different strakes. The draftsman should always endeavor to lay out work and arrange the steel structure so that this economy can be obtained wherever possible.

15. Next draw the inner-bottom plating. The half width of the center strake, 21 inches, is laid off to the right of the center line, and the edge laps and other strakes are laid in a manner similar to those of the shell. The width of the inner-bottom strakes is 6 feet 2 inches and the edge lap on the center strake is $4\frac{1}{2}$ inches and on the other strakes $2\frac{1}{2}$ inches. If fuel oil is to be carried in the double bottom, all seams must

be double-riveted. The margin plate, shown in Fig. 2, is drawn with its outboard surface coincident with the molded line, the heel of the margin angle being on the molded line at the shell. The inner edge of the margin plate is 11 inches inboard of the intersection of the margin line and the tank-top molded line continued, the margin plate being bent to a 2-inch inside radius at this intersection. The under sides of the *in* strakes are coincident with the molded line of the tank top. A check on the dimensions and laps of the tank top is as follows: $21''+3(6'\,2'')+11''-(4\frac{1}{2}''+3\times 2\frac{1}{2}'')=20$ ft. 2 in., which, as shown in Fig. 2, is the molded half width of the tank top. That is, the sum of the half center strake, other strakes, and the lap of margin on top line, less the seams, is equal to the half molded width of the tank top.

16. Draw the center-line keelson as a heavy line directly on the center line of the vessel. This plate extends from the keel to the inner bottom. Draw the top and the bottom angles of the sizes shown. The object of the half siding *k*, Fig. 2, is to permit the lower center-keelson angles to be flat. If the bottom molded line extended to the center line, there would be a closed bevel in the bottom angles; but, with the 6-inch half siding, the knuckles in the keel occur 6 inches each side of the center and the angles at the bottom of the center-line keelson are not beveled. Both the top and the bottom keel angles are continuous fore and aft; that is, the several bars, each 40 to 60 feet long, are connected at their ends.

17. Draw the side-keelson plates with their inboard sides coincident with the molded line of the inner bottom, and their outboard sides on the molded lines of the ship; also draw the top and bottom angles. These angles are not continuous, but are intercostal between the floors, their respective heels being at the intersection of the molded keelson line with the shell and with inner-bottom surfaces.

Draw also the continuous angle that connects the bottom of the margin plate to the shell.

18. The floor plate extends from the center-line keelson to the margin and from the shell to the inner-bottom plating. This

plate is connected to the center keelson by double angles, one on the forward side of the floor plate and one on the after side. These cannot both be seen and accordingly have to be indicated by the word *double*. At the point of juncture of the two floor plates (port and starboard) and the center-line keelson there will be four angles, two to port and two to starboard. Draw these angles extending to within ½ inch of the toes of the top and bottom angles.

Next draw a diagonal line at the top inboard corner of the floor plate to indicate that a piece is cut off to permit the top keel angle to be continuous. Likewise show the part cut out at the bottom inboard corner to allow the bottom keel angle to pass through and for drainage. Then, at the top outboard corner of the floor plate, draw a diagonal to indicate that the floor plate is cut to clear the curve of the margin plate. These holes at the corners also allow air to pass freely in the tank and prevent the formation of air pockets that would hinder the water ballast from filling the tank.

19. Draw the frame angle in the inner bottom from the half siding line *k*, Fig. 2, to the margin plate. The heel of this angle is on the molded line on the in shell strakes. The line indicating the lower edge of the horizontal flange of the angle may be considered to coincide with the top of the shell plate, as drawn at strake *A*, or it may be drawn separate as shown at strake *B*. As the frame is joggled over the in strakes, the heel is against the out strakes as well as the in strakes. The angle connecting the floor to the margin plate is next drawn; this extends from about ½ inch above the frame to the curve at the top of the plate. The reverse frame is then drawn from the top keel angle to the margin angle, space of about ½ inch being left at each end. This angle is joggled over the inner-bottom plating and, like the frame, is continuous, passing through the side keelsons through openings not shown in this view. Draw angles connecting the side keelsons to the floor. Indicate by small solid ovals the air holes through the floor plate and the reverse frames to prevent the formation of air pockets. Similarly, show in the lowest corners of each bay of the floor drain

holes 2 inches in diameter and flush with the top of the frames to allow water to pass freely fore and aft. Finally the work in the inner bottom is completed by showing the lightening holes, size 24 in.$\times$18 in. There are two of these in each floor plate, and the inboard edge of the inboard hole is in each case 10 inches from the center-line keelson or the side keelson. The distance between the holes is 12 inches and their horizontal centers are on a line half way between the top and the bottom of the floor.

20. When angles have been designated as extending to a point $\frac{1}{2}$ inch from another, this is merely for making the drawing, the actual clearance between angles depending on the riveting and the leeway or variation, allowed when ordering material. Frequently material is ordered *plus or minus* $\frac{3}{8}$ inch; which means that a variation of $\frac{3}{8}$ inch either way will not condemn the part. In such cases the end rivets of the part are definitely located. The center of these must be not less than $1\frac{1}{2}$ times the diameter of the rivet from the end of the part. A variation of $\frac{3}{8}$ inch either way necessitates an allowance in fixing the location of the end rivets so that with the maximum allowance of plus $\frac{3}{8}$ inch the ends will not interfere with the adjoining members, and so that with the minimum length the centers of the end rivets will not be less than one and one-half diameters from the end. However, there are parts that must be ordered exact. In any case it is not practical on a drawing made to the scale of this plate to indicate less than an inch. When angles are double it frequently happens, as in the angles connecting the center-line keel to the floors, that they cannot be so shown on the drawing, but the lettering must be the means of expressing that. In the case of the vertical angles connecting the floors to the side keelsons, which here are intercostal—that is, they are cut at each floor—there must be two angles, the one on the side of the frame and reverse frame and a corresponding angle on the far side.

It will be noted that the angles connecting the side keelsons and the shell are on the inboard side of the keelsons. While it would not make much difference in this particular case if they were on the outboard side, yet if there were a large dead rise

these angles would then have a closed bevel and it would be difficult to drive rivets.

21. From a point on the molded line of the vessel, 3 feet 6 inches above the base line, draw the 10-inch bulb-angle frame outside of the inner bottom. Note here that neither shell nor frame is joggled. From about the toe of the angle connecting the shell and the margin, draw the frame angle that connects the shell to the bilge bracket. This frame angle extends to the bulb frame. Locate the top of the bilge bracket 6 feet 6 inches above the base line. Draw the top parallel to the base line and extending slightly inside the bulb frame and then down to the intersection of the molded lines of the tank-top plating and the margin. This bracket is flanged (away from the view point) and the lower inboard corner is cut off, as shown, to allow the margin angle to be continuous. Draw the angles connecting this bracket and the margin plate; these angles are double as noted. Show the lightening hole 18 inches in diameter 12 inches from the top of the bracket flange and 15 inches from the molded margin lines.

22. Next, in pencil and not for inking-in, draw a line cutting the molded deck lines 9 feet and $\frac{1}{2}$ inch from the center line. Draw the deck beams up to this line, which is in line with the heel of the angle connecting the hatch coaming and the deck plating. Note that the deck beams face away and consequently the flange line and bottom of the bulb line are dotted; also, as the deck-beam brackets come between the frame and the beam, the top of the bulb line is dotted behind the bracket. These brackets overlap the frame six times the diameter of the rivets connecting the brackets and frames. As these rivets are $\frac{7}{8}$ inch in diameter, the lap is $5\frac{1}{4}$ inches. This is also the width of the bracket at its tapered, or narrow, end on the beam. The second-deck beam bracket is 39 inches deep below the top of the beam and 39 inches wide from the outboard edge. This size is written $39'' \times 39''$. Similarly, the shelter-deck beam bracket is $22'' \times 22''$. The deck beam does not extend to the shell, but only to the edge of the bracket. Draw the deck stringer plate—that is, the outer strake of deck plating—that of the shelter

deck being 50 inches wide, and that of the second deck 56 inches wide. The stringer plates are in strakes.

23. As the hatches are usually the same width on each deck, it is desirable to have a deck-plate seam run along at the outboard edge of the hatches, so as to avoid cutting into the deck plate next to the hatch, therefore the deck-plate strakes are made of such width that the edge of the one next the hatch comes up against the coaming, which is the vertical $\frac{1}{2}$-inch plate forming the wall around the hatch opening.

The edges of the deck plates and the edge lap to the stringer are single-riveted, the lap of the deck plates being $2\frac{1}{4}$ inches wide and the lap on the stringer $2\frac{1}{2}$ inches. It is obviously convenient to have the two strakes of plating the same width. The half width of the second deck is 24 feet $10\frac{1}{2}$ inches (see offset table) and as the strake of shell plate at this deck is an outside strake and is outside the molded line, the total width will be increased by the thickness of the strake below, which is .66 inch, making the total half width 24 feet $11\frac{1}{8}$ inches. The distance between the inner edge of the stringer plate and the hatch coaming is $24'\ 11\frac{1}{8}'' - (9'\ 0\frac{1}{2}'' + 56'') = 11$ feet $2\frac{5}{8}$ inches. The lap of the plate on the stringer being $2\frac{1}{2}$ inches and the lap of the two plates being $2\frac{1}{4}$ inches, the total width of the two plates is $11'\ 2\frac{5}{8}'' + 2\frac{1}{2}'' + 2\frac{1}{4}'' = 11$ feet $7\frac{3}{8}$ inches, or 5 feet $9\frac{11}{16}$ inches each. The outer deck plate is joggled over the stringer plate and the inner deck plate. The stringer plate is notched to permit the frames to pass through. Draw the shell clips, which are in short lengths between the frames and which connect the stringer plate and the shell plate; also draw the stringer angle along the face or inner edge of the frames, also, by dotted lines, show the clip on the far side of the frame in way of this stringer angle. The space between the shell clip and the stringer angle is usually filled by a wood chock set in and covered by cement. This chock and cement make the deck at this part nearly water-tight. From $2\frac{1}{2}$ inches outboard of the inner edge of the stringer, lay off 5 feet $9\frac{11}{16}$ inches, the width of the outer strake of plating, and obviously the next strake will be of the same width, extending from the outer sur-

face of the hatch coaming plate to $2\frac{1}{4}$ inches outboard of the inboard edge of the first strake.

24. In like manner lay off the shelter-deck plating, the width of the two strakes being 5 feet $7\frac{1}{4}$ inches each, determined the same way as for the other deck, but the lap on the stringer plate is 3 inches and the lap on the two plates is $2\frac{1}{2}$ inches, because a heavier plate is used. Here the stringer shell-angle which connects the shell and the stringer plate is the stringer angle and is continuous. The sheer strake must always extend above this angle sufficiently far that in the butts of the sheer strake there may be two rows of rivets above the angle.

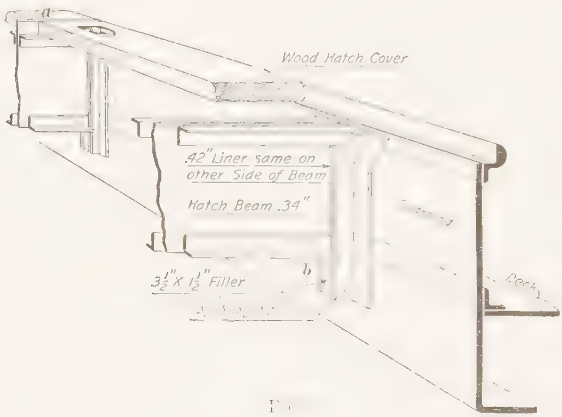
25. The coaming plate of the second-deck hatch extends 10 inches above the molded deck line and 18 inches below, and is flanged or bent 9 inches outboard. The coaming forms a girder supporting the deck beams on the outboard side and the hatch beams on the inboard side. The deck beams are connected to the coaming by single clips on the near side (away from the flange). The coaming flange, being wide, would buckle if it were not supported and held in its place. This is accomplished by a bracket riveted between the clip and the deck beam; this bracket is $7\frac{1}{2}$ inches wide and has a flange 3 inches wide on the outboard side. These brackets are on alternate beams and are connected to the flange of the coaming by an angle clip. As these brackets are not on every frame they are shown dotted in the drawing.

Next draw the angle connecting the deck to the coaming. This is riveted to the coaming plate and to the deck plate and is called the coaming angle. Finally a $2\frac{1}{2}$-inch half-round (one-half of a round $2\frac{1}{2}$ inches in diameter) is drawn at the top. This serves to stiffen the coaming and also prevents damage of cargo against a sharp narrow edge.

26. The wooden covers over the hatch opening run fore and aft (longitudinally) and their tops set about a half inch above the coaming plate. The covers rest on hatch beams spaced 4 feet 2 inches apart, two of which and their supports are shown in Fig. 5.

Each beam consists of a plate, 17 inches deep below the covers, and stiffened by 3″×4″ angles on each side at top and bottom. In alternate hatch beams, the plate is increased 2 inches in depth so that it extends 2 inches above the double top angles, as shown in Fig. 5 at *a*, so that the ends of adjacent wood covers, which are two hatch-beam spaces in length, will be separated, an end of each resting on each side of the plate.

On each side of the beam, at the ends, are doubling pieces .42 inch thick, which make the width of the beam ends 1.18



inches, thus furnishing a good thickness for the beam to rest on.

The supports for the hatch beams are made of two 3½″×3½″ vertical angles riveted to the coaming and separated by a 1½-inch filler that is riveted through the two angles. This filler furnishes support for the beam ends, as shown at *b*, and the angles are spread at the top to facilitate placing the beams.

The wooden hatch covers are each about 24 inches wide and have recessed handles on the top so they can be lifted by a man at each end. The hatch cover as a whole is made water-tight by means of heavy canvas tarpaulins that are secured to the coaming plate by means of steel strips and wedges.

27. In drawing the lower hatch on the plate, first draw the top of the wooden cover slightly above the hatch coaming—½

inch to be exact, but this will be difficult to show on this scale. Then draw the bottom of the covers, which are $2\frac{1}{2}$ inches thick. Each cover may in this case be made 22 inches wide so as to show five separate covers on the plate. Draw the bottom of the beam 17 inches below the bottom of the wooden covers. Then draw the vertical angles of the beam supports, which are riveted to the coaming plate; only one of the supports can be seen in this view, so the construction will have to be indicated by the lettering. Next draw the top and bottom angles on the beam, the top angles extending to the ends of the beam and the bottom one to within about $\frac{1}{4}$ inch of the vertical angles of the beam supports.

28. The shelter-deck hatch is similar to that of the second deck, except as noted on the drawing. The coaming is 30 inches high to the top of the hatch section, which is similar to a **Z** bar with a half-round for one flange. This hatch section, marked *P. S. Co. Hatch Section,* because made by the Pennsylvania Steel Co., forms a rest for the edge of the hatch cover. In order to shed water, the center of the hatch on the weather deck is made higher than the sides.

To draw this hatch, locate the top of the wood covers at the center line, by measuring up from the point where the molded line of the shelter deck (top of the deck beam) crosses the center line of the ship a distance of 34 inches; from this point to a point $\frac{1}{2}$ inch above the top of the hatch section at the side, draw a line representing the top of the wood covers; these covers are 3 inches thick. Draw the bottom of the hatch beam 27 inches below the bottom of the cover at the center line and parallel to the base line. The vertical double angles forming part of the beam rest, only one angle of which can be seen in the view, extend 3 inches below the molded deck line at the side; in other respects the supports and beam are similar to those of the second-deck hatch.

As the coaming stands high above the deck, it is necessary to support it in some way to prevent it from buckling when the deck is under compression when the ship is in the hollow of a wave. This is accomplished by means of triangular brackets

(not shown) connecting the side coaming and the deck plating. Sometimes a horizontal stiffener is fitted to the coaming at about one-half its depth.

29. To enable the deck beams to carry the loads upon the decks and not be of excessive size, intermediate supports are provided. The supports are known as *pillars,* or stanchions, and are fitted as a single row on the center line of the vessel, or, they are placed in a row on each side of the center line at or near the sides of the hatches, or both. Formerly these pillars were fitted to every beam and later to alternate beams. This required a girder at the head to support the intermediate beams. Now it is quite general to have the pillars widely spaced—from 12 to 20 feet—and to have a strong girder at their heads to support the intermediate deck beams.

30. The ship here illustrated is used for carrying grain, and as this cargo is easily shifted in a seaway, or rough sea, it is usual in such vessels to provide a center-line partition of wood. These wooden planks are about $2\frac{1}{2}$ inches thick and are placed horizontally on their edges and supported by a row of center-line pillars staggered alternately to the two sides, so that the planks may be supported between them. Pillars are fitted at the corners of the hatches, and these are to be drawn dotted as shown. The center line of the pillars is 10 feet 1 inch from the center line of the vessel. Lower pillars are solid and $4\frac{1}{2}$ inches in diameter, and upper pillars, also solid, are $3\frac{1}{4}$ inches in diameter. The feet of the pillars are forged out into a palm which takes two rivets. These rivets for the lower pillars, or stanchions, extend through a small doubling plate (not shown), the inner-bottom plate, and the reverse frame. The rivets for the feet of the upper pillars extend through the deck plate and the deck beam flange. The heads of the pillars are flattened out vertically and riveted to the deck-beam webs. The pillars along the center of the vessel are similar in all respects to those just described.

31. The detail of the horizontal gusset plate over the bilge bracket is next to be drawn. This view is a plan of the bracket, with the part along the bilge bracket expanded into the hori-

zontal plane. First draw the near face of the bilge bracket in pencil $2\frac{1}{16}$ inches above the base line. Next draw in pencil the line (vertical on the drawing) representing the intersection of the molded lines of the tank top and the margin plate. Draw the outer edge of the outer strake of inner-bottom plating and the inner edge of the margin—the latter line dotted. The inner-bottom plate and the margin plate are shown broken away. Draw dotted the far face of the bilge bracket, and also $3\frac{1}{2}$ inches from the near face of the bilge bracket draw the edge of the flange. Part of this latter line will be full and part dotted; as is also the line representing the near edge. Draw two dotted lines in line with the bilge bracket and to the left of the margin line to represent the floor inside of the double bottom, and beside it draw the three dotted lines representing the reverse frame in the inner bottom. The floor is shown continuing up to the bend in the margin, but the reverse frame extends as shown in the elevation. The gusset extends from the intersection line of the margin 5 inches toward the center line of the ship and extends fore and aft 10 inches each side of the center line of the bilge-bracket flange, allowing for five rivets through the margin-plate flange. The transverse dimension of .the bracket is 24 inches measured from the inboard edge out along the bilge-bracket flange. Draw the diagonal sides of the bracket as shown. There are shown also five rivets connecting this bilge gusset plate to the bilge-bracket flange. The part of the bilge-bracket flange and the part of the margin under the gusset plate are dotted.

Also show the gusset in section (full thick line) on the main drawing.

32. To keep the cargo off the steel tank top and out of the bilge, a wood ceiling is laid. This is of $2\frac{1}{2}$-inch spruce or yellow pine, laid fore and aft, and fastened to $2'' \times 3''$ wooden *grounds* laid transversely at each frame. These grounds are not fastened to the steel work, but are laid in a mixture of tar and cement while the mixture is wet. As it hardens it firmly secures the grounds. The sheathing or ceiling is frequently made in sections that can be removed to examine the steel work.

Over the bilge brackets the ceiling is directly bolted to the flange. A small angle clip is riveted to the web of the frame on the side opposite the bilge bracket and takes one end of a wooden chock which forms the top of the bilge ceiling, the other end resting on the edge of the bilge bracket. This chock is a tight fit and should slope inboard so water or dirt will not lodge against the shell. The drawing of this ceiling is quite plain —the widths of the planks being about 10 inches on the tank top, and to suit conditions over the bilge.

33. On some vessels the ceiling on the bottom is entirely omitted except under the cargo hatches, but the bilge ceiling is, of course, fitted. In such cases the tank top should be protected by a heavy coat of Stockholm tar and cement or bitumastic cement.

34. Above the bilge ceiling, cargo is prevented from chafing against the frames by the wooden cargo battens that extend longitudinally throughout the holds. These battens are of spruce or yellow pine and in this case are 6 in.$\times$2 in., which is about the usual size. They are spaced on 12-inch centers, or separated 6 inches, and are attached to the frames by forged or cast cleats which permit their easy removal. Where channel frames are used, the battens may be attached by bolts. Attachment is on every third or fourth frame. To draw these, locate the first one 6 inches above the top of the bilge ceiling and then draw the battens 6 inches apart. In the 'tween-decks space, the lowest batten is just above the $3\frac{1}{2}''\times3\frac{1}{2}''$ stringer angle bar, and the rest are spaced 6 inches apart. These battens are shown with the usual hatching to represent wooden ends.

35. The bilge keels, so called because they are on the bilges and are similar to the old-fashioned outside keel, are put on each side to assist in preventing excessive rolling of a ship in a seaway. They project out from the ship about perpendicular to the shell plating. This keel is drawn with the back of the outstanding flange of the $7''\times3\frac{1}{2}''\times.50''$ angle on a line 45° to the base line and passing through the intersection of the deadrise line and the side line. The 11-inch plate laps 3 inches on the angle, as shown, and its outer edge is stiffened by the half

round. Rivets connecting the plate and angles are wider spaced than the rivets connecting the angle and the shell—usually about twice as far apart. By this arrangement, if the end of the bilge keel strikes anything, the keel will be broken at a joint in itself instead of tearing out the rivets connecting it to the shell. This prevents leaks into the vessel and makes repairs simpler. The bilge keels extend from one-quarter to one-half of the vessel's length, depending on the fullness of the vessel. They follow somewhat the line of the bilge diagonal so as to add as little resistance as possible to the vessel's progress through the water.

36. The drawing having been made, it is to be finished by putting on the lettering, as shown on the plate. The title and number of the plate are also to be put on as shown.

As the lettering refers to certain constructions and details that are peculiar to ship drafting, these peculiarities will now be explained.

Fore-and-aft plates—those that run lengthwise—are indicated by two dimensions, the width and the thickness, as the shelter-deck stringer plate 50 in. $\times$ .52 in. Thicknesses are here indicated by hundredths of an inch. As the greatest stress generally comes on the middle portion of a vessel, the greater weight of material is required there to meet these stresses, and as the stresses reduce toward the ends the weight or thickness of material may be reduced. The greater thickness extends for one-half the length of the vessel and then it tapers gradually to the thickness given for the ends. The shelter-deck stringer plate is reduced to 33 inches wide and .42 inch thick at the ends. The shelter-deck plate is .36 inch thick for the middle half length and .34 inch thick at the ends before reaching the peak tanks, and .32 inch thick over the peak tanks. This change is due to the fact that wide frame spacing, 30-inch, is adopted, and to allow for this the deck plating is made thicker in way of it, but as the frames in the peaks, or extreme end compartments used for water ballast, are spaced only 24 inches apart, the thickness is reduced to .32 inch.

37. Butts of all strakes or lines of plates must be properly shifted from butts in adjacent and next adjacent strakes—that

is, butts in adjacent strakes, or next adjacent strakes, must not be in line—so as to make the strength somewhere near uniform. Where the thickness is to be reduced at half length, it is of course not always possible to have the reduction at exactly that point, but at the first butt beyond that point the thickness is changed.

38. The thickness of transverse members changes at the frame immediately beyond the half length. In way of the boiler room, all parts of the inner bottom, except those that are attached to the outside plates and covered with cement, are increased in thickness, the angles .10 inch and the plates .10 inch to .04 inch, depending on the size of the ship.

39. Except where fuel oil is carried in the inner bottom, all parts of the inner bottom are usually covered by some protective coating to prevent deterioration from the dampness. This deterioration is specially active under the boiler space, and hence the increase in thickness of parts. On the bottom there was formerly always laid a mixture of Portland cement and fresh-water sand, but this is very heavy and subject to cracks. Present-day practice is to employ some bitumastic coating that is much lighter than the cement and, being plastic, will not tend to break away from the steel structure. A heavier coating is used on the bottom than on the under side of the tank top, the floors, and the keelsons. This coating is also usually applied to the entire surface of coal bunkers to prevent corrosion by the coal.

40. Sometimes the size and spacing of rivets in different parts of the structure is put on the cross-section drawing, but that has been omitted here. Riveting schedules, however, will be found on some of the detail structural drawings to be made further on. The riveting tables of Lloyd's Register of Shipping have been given in *Ship Drafting,* Part 1.

41. Classification Rules.—In the lettering on the plate it will be noticed that the principal dimensions are given, also that this particular vessel is classed at Lloyd's.

All classification rules prescribe very particularly the sizes, weights, and proportions of the various parts of vessels, also the equipment required to be carried; and a vessel not built substantially in accordance with the rules would receive a lower rating and hence might be penalized by high insurance rates. In the rules, the sizes and arrangement of various parts are based on factors derived from certain measurements of the ship. These factors are given as *1st Number, 2nd Number* etc., and as ratios between certain dimensions.

The *1st No.* and *2nd No.* given on the plate are the numbers in Lloyd's tables of scantlings, or sizes of parts, that fit this particular vessel. The **1st No.** is the sum of the molded beam and the molded depth to the deck below the shelter deck, when that deck is 8 feet or less below the shelter deck. For full-scantling vessels, this depth is to the top deck, or upper deck as it is then called.

The **2nd No.** is the product of Lloyd's length (350.5 feet) and the 1st No. Lloyd's length is measured from the fore side of the stem at the second deck to the after side of the stern post in shelter-deck vessels. In full-scantling vessels it is measured between similar points but on the upper continuous deck. The expression $\frac{L}{B}$ is the ratio of Lloyd's length to the beam; and $\frac{L}{D}$ is the ratio of Lloyd's length to the molded depth measured to the upper continuous deck—in this case the shelter deck; and d is the depth from the top of the inner bottom to the top of the lowest tier of beams. In this vessel extra-large bilge brackets and second-deck beam brackets are fitted, hence a modified d value is given.

42. The size of frames above the double bottom and their spacing is governed ordinarily by the *1st No.* and d. The size of the upper-deck plating, upper-deck stringer and stringer angle, sheer strake or top strake of the shell plating, and of the strake below, are governed by the *2nd No.* and the ratio $\frac{L}{D}$. The remainder of the shell, the flat plate keel, and the second-deck plate and stringer, and all parts of the inner bottom are

determined by the *2nd No.* Size of deck beams is determined by their length and the number of rows of pillars.

43. Comparatively few vessels are built exactly in accord with classification society rules, as usually some irregularity is introduced somewhere that justifies or requires change in the sizes of parts in other places. In the case of the ship here drawn, the rule spacing—that is, spacing required by the rules—of frames is 25 inches, but 30-inch spacing was used, and this change required corresponding change in the size of frames, shell plating, deck plating, and inner-bottom framing.

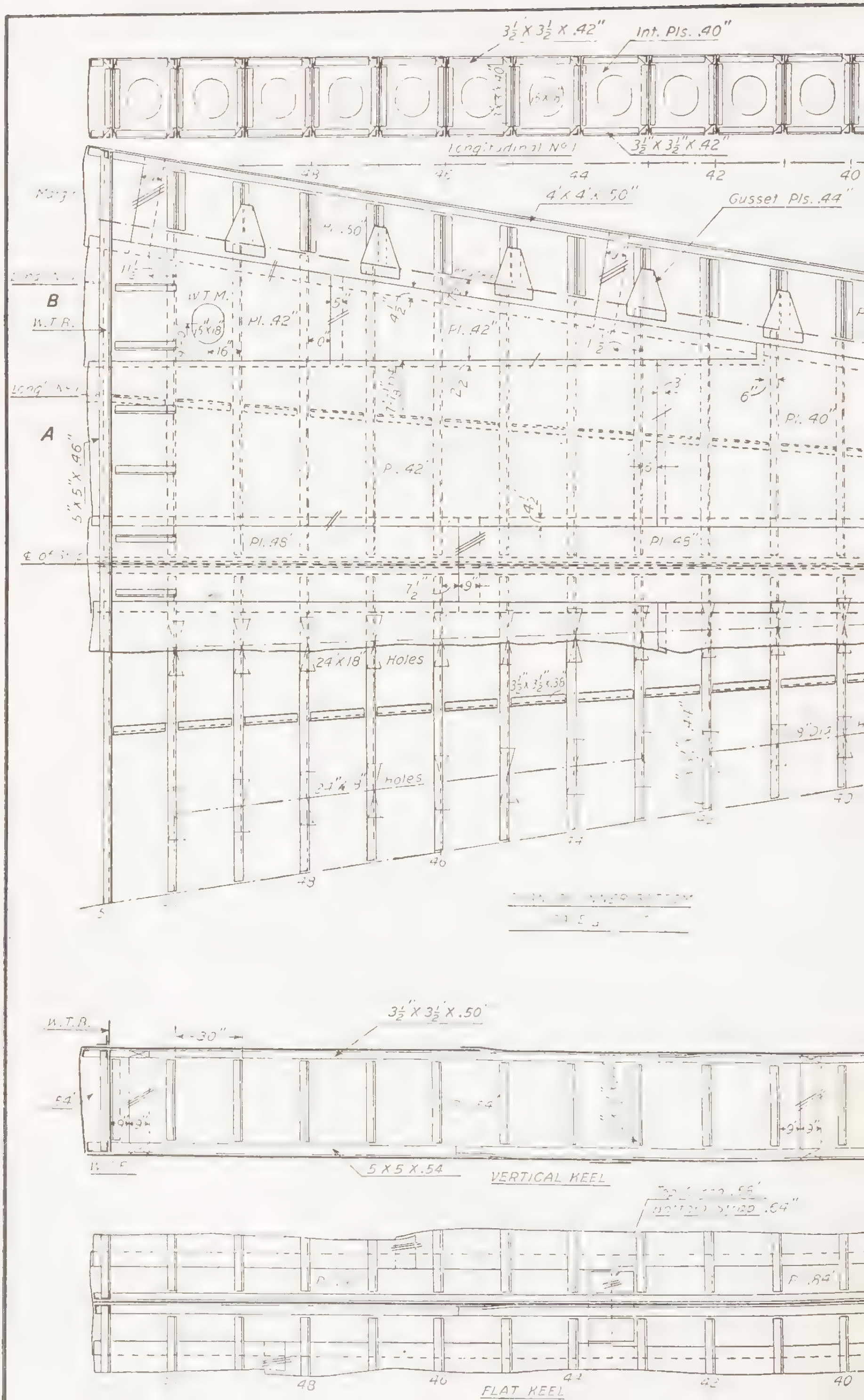
44. Another number not here shown is the Equipment Number, which depends on the size of poop, bridge, forecastle, and deck houses. This number regulates the weight of the anchors and the size and length of the anchor chains and wire and manila hawsers required to be carried on the vessel.

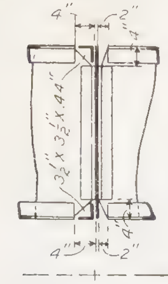
PLATE 1053: TITLE, KEEL, VERTICAL KEEL, INNER BOTTOM, AND LONGITUDINAL

45. Plate 1053 shows the construction of the flat keel; the vertical keel, or center-line keelson; the inner bottom, or tank top; and the longitudinal, or side keelson. To make plain the general appearance and construction of these parts of a ship, Figs. 6 and 7 are introduced.

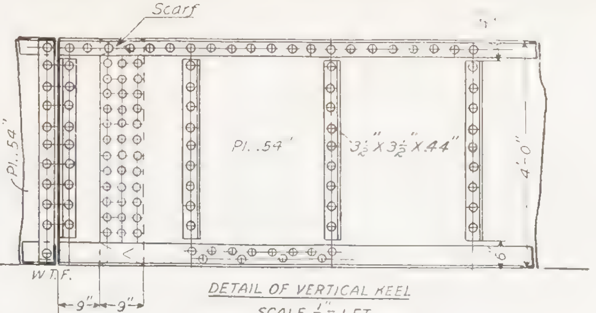
Fig. 6 shows the keel structure of a large ship as it appears to a person looking toward the stern. Fig. 7 shows the same keel after there have been added to it the floors, the margin plates, one of the side longitudinals, and some of the aftermost frames, the latter indicating quite plainly the shape of the vessel's stern.

46. To draw the plate, begin with the plan of the Flat Keel, and draw in connection with it the elevation of the vertical keel as shown on the plate. Beginning at a point $\frac{3}{4}$ inch from the left-hand border line of the plate and 1 inch above the lower border, draw the center line of the flat keel. Except

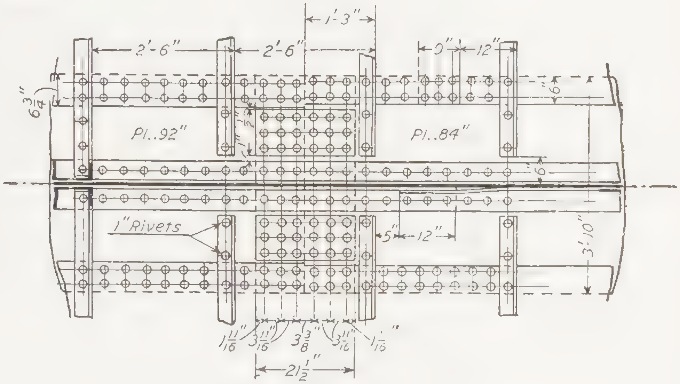

3½ X 3½ X .42"
Int. Pls. .40"
Longitudinal No 1
3½" X 3½" X .42"
48
46
44
42
40
4' x 4' x .50"
Gusset Pls. .44"
B
W.T.R.
W.T.M.
15 x 18
16"
Pl. .42"
Pl. .42"
A
5" x 5" x .46"
Pl. .40"
P. .42"
Pl. .45"
Pl. .45"
24 X 18" Holes
3½" x 3½" x .36"
holes
W.T.R.
30"
3½" X 3½" X .50"
5 X 5 X .54
VERTICAL KEEL
FLAT KEEL



DETAIL OF LONG'L Nº 1
SHOWING CUTS AT FLOORS.



DETAIL OF VERTICAL KEEL
SCALE $\frac{1}{2}$" = 1 FT.



DETAIL OF FLAT KEEL
SCALE $\frac{1}{2}$" = 1 FT.

RIVETING INSTRUCTIONS

CONNECTION	DIA. OF RIV.	SPACING	
		DIA'S	INCH
Bottom Keel Angles to Keel Plate	1"	$4\frac{1}{2}$	$4\frac{1}{2}$"
Bottom Keel Angles to Vertical Keel	$\frac{7}{8}$"	5	$4\frac{3}{8}$"
Top Keel Angles to Vertical Keel	$\frac{7}{8}$"	5	$4\frac{3}{8}$"
Butts of Vertical Keel (Treble)	$\frac{7}{8}$"	4	$3\frac{1}{2}$"
Butts in Flat Keel	$1\frac{1}{8}$"	See Detail	
Seam Flat Keel to Adj. Shell Strake $6\frac{3}{4}$" Wide	$1\frac{1}{8}$"	4	$4\frac{1}{2}$"
Seam Flat Keel to Adj. Shell Strake 6" Wide	1"	4	4"
Vertical Clips to Vertical Keel	$\frac{7}{8}$"	5	$4\frac{3}{8}$"
Butts Middle Strake Inner Bottom	$\frac{7}{8}$"	4	$3\frac{1}{2}$"
Seams Inner Bottom $5\frac{1}{4}$"	$\frac{7}{8}$"	4	$3\frac{1}{2}$"
Seams Inner Bottom $2\frac{1}{2}$"	$\frac{3}{4}$"	4	3"
Bounding L to Margin	$\frac{7}{8}$"	$4\frac{1}{2}$	4"
All Angles to Longitudinal	$\frac{3}{4}$"	7	$5\frac{1}{4}$"

Note: Frame Spacing 30"

5 x 5' x 54"

KEEL, VERTICAL KEEL, INNER BOTTOM AND LONGITUDINAL

DRAWN BY ____________
DATE ____________

1053

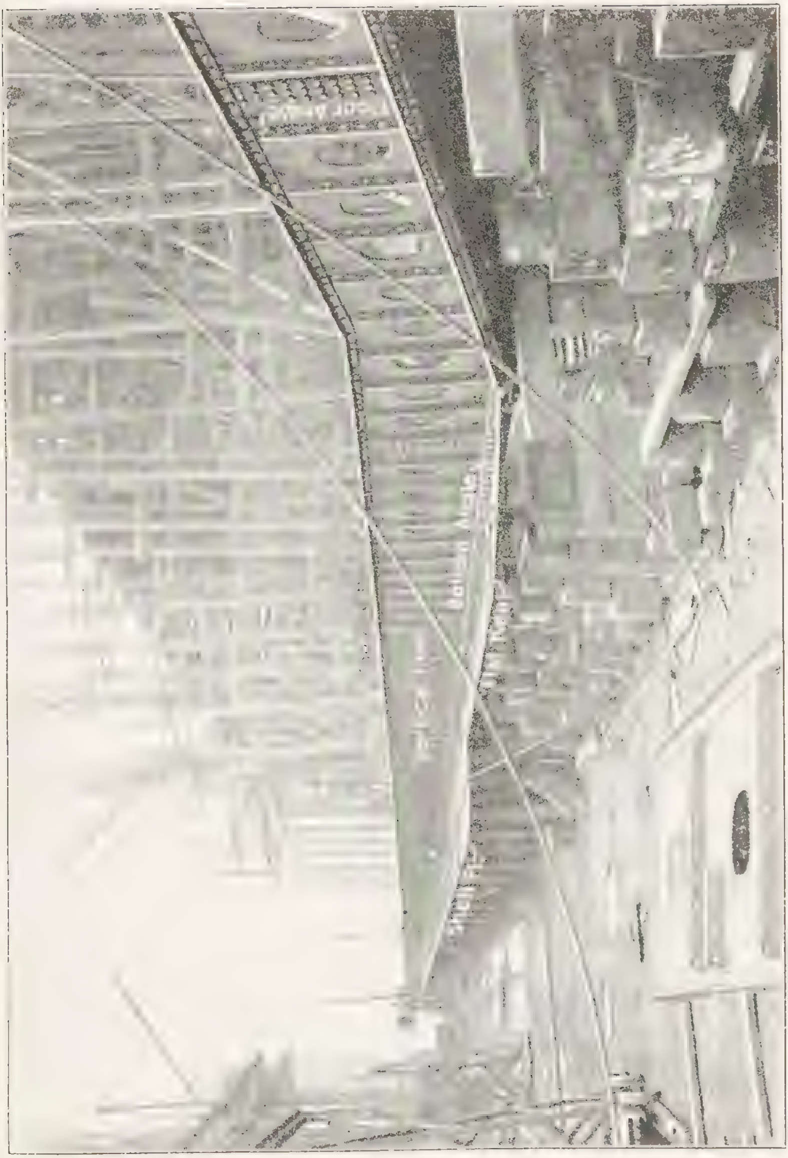


FIG. 6

Fig. 7

where otherwise noted on the plate, the drawings are to be made to a scale of $\frac{1}{4}$ inch=1 foot.

On the center line of the plan, lightly tick in in pencil each of the molded frame lines, fourteen in all, the first 1 inch, actual measurement, from the left-hand border and the others 30 inches apart to scale. Number the frames as shown. Then draw the side lines of the flat plate keel 23 inches each side of the center line; these are dotted lines, as the keel is an outside strake and the strake of shell plating next the keel is an inside strake.

Next locate the butt joint in the keel plate, half way between frames *43* and *44*; this is also shown as a dotted line, as double

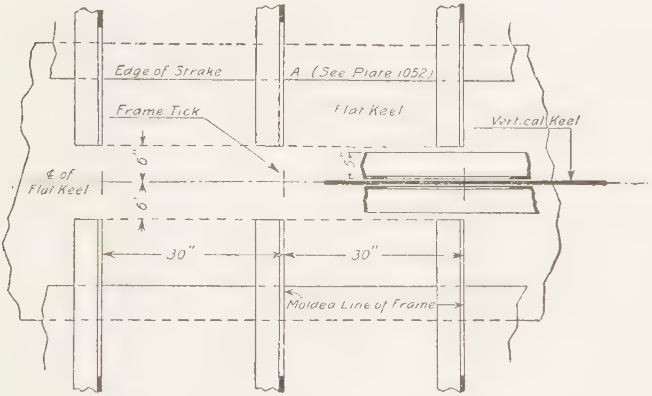


FIG. 8

butt straps are fitted. The forward plate is .84 inch thick and the after plate is .92 inch.

Draw lightly a pencil line 6 inches each side of the center line, as the dotted line in Fig. 8, to indicate the termination of the frames inside the inner bottom. These frames may be drawn next in the manner shown in Fig. 8, each in three full lines, the first in line with one of the frame ticks previously made and the other two representing respectively the toe and the flange of the frame, which is a $3\frac{1}{2}'' \times 3\frac{1}{2}''$ angle.

As a water-tight floor (W. T. Fl.) is fitted on frame *51*, this frame will extend to the vertical keel plate and be continued up

on the center keelson in the manner shown in Fig. 9, where it is called a *bounding bar;* it is therefore indicated in section, as is shown more plainly on the left-hand frame in the plate in the Detail of Flat Keel.

47. Draw the center keelson as a heavy line with its center on the center line of the plan; then draw the angles connecting the center keelson and the flat keel, in the manner shown in Fig. 8. These are 5 in.×5 in.×.54 in. and are indicated by two lines each, one showing the toe of the angle 5 inches from the side of the keelson plate, and the other quite near the keelson and representing the vertical flange.

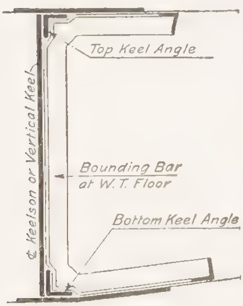


FIG. 9

Indicate the overlapped butt in the angles on the starboard side of the keelson plate. The end of the after angles is 17 inches forward of the frame *46*, and the forward angle laps 12 inches over the the after one. The vertical flange of the forward angle leaves the vertical keel 11 inches forward of the butt, and a tapered filler is fitted in the space forward of the after angle, between the vertical keelson and the forward angle. A similar arrangement of a filler is used on the lower, or horizontal, flange of this angle. A similar angle connection would be made in the angle on the port side of the keelson, but at another place to avoid butts coming opposite each other.

48. In Table I, given in *Ship Drafting,* Part 1, it will be seen that the required edge lap for a .92-inch plate is $6\frac{3}{4}$ inches and the lap for an .84-inch plate is 6 inches. Hence the laps of the shell strake next to the flat keel are to be drawn $6\frac{3}{4}$ inches and 6 inches, according to the weight of the shell plate, the break of course coming at the butt of the plates. As this shell strake is an inside strake, these lines will be full except in way of the frames. The 9-inch butt laps, 12 inches aft of frames *46* and *48*, are also to be indicated, the butts being located in the manner shown in the Detail of Flat Keel. The butt straps on the flat keel are also to be drawn to the dimen-

sions given in the detail drawing, the inner, or upper, strap being shown in full lines and the outer one in dotted lines. Note that the inner strap is in two parts, one part on each side the center-keelson angles and extending to the shell strake next the keel, with clearances of 1 inch and $\frac{1}{2}$ inch, as indicated. The outer, or bottom, strap extends clear to the edges of the keel plate. The type of butts is to be indicated in the manner shown in Fig. 29 in *Ship Drafting*, Part 1, and the lettering completes the plan of the flat keel.

49. Next draw the Vertical Keel, or center-line keelson. First draw a line $2\frac{5}{16}$ inches above the border line of the plate, to represent the bottom of the vertical keel, and in length and location corresponding to the center line of the plan of the flat keel. The vertical keel is 48 inches deep; therefore, 48 inches, to scale, above this line draw a line to represent the top of the keel; this line will represent also the molded top of the inner bottom, or tank, and corresponds to the bottom of the center-line strake of the inner-bottom plating.

The molded base line is above the top of the flat plate keel, which should next be drawn as a heavy line; on this should also be shown the projection of the outer butt strap, the location of which is determined from the plan. The inner butt strap, not extending under the angles, does not appear in this view.

Five inches above the top of the flat keel, draw the top of the $5''\times5''\times.54''$ angle that connects the flat and the vertical keels. Show the lower flange of this angle and the projection of the butt shown in the view of the flat keel. Also show the $3\frac{1}{2}''\times3\frac{1}{2}''\times.50''$ angle connecting the vertical keelson to the center-line strake of the inner bottom. The butt forward of frame *43* is drawn similar to that in the lower angles.

50. Next, from the molded frame lines in the plan of the flat keel, locate the heels of the $3\frac{1}{2}''\times3\frac{1}{2}''\times.44''$ vertical angles that connect the floors to the center vertical keelson, and draw them; as shown in Details of Vertical Keel, on the plate, they extend from 6 inches above the bottom of the keel plate to $4\frac{1}{2}$ inches below its top. At the water-tight floor, double angles

are drawn, the heel of that on the after side being on the frame line and extending to the inner bottom and the flat keel, the angle being made in the form shown in Fig. 9. Draw the heavy solid line representing the floor, with its after side on the frame line. Forward of the floor is an angle clip similar to those on the other frames. The after angle is shown in heavy solid section at the top and bottom, as it is continuous toward the view point.

Draw the butt laps in the vertical keel forward of frames *51* and *41*, the crosses in the way of the top and bottom angles indicating scarf joints, the construction of which was shown in Fig. 30 of *Ship Drafting,* Part 1. Lay off the center-line strake of the inner-bottom plating, making this a heavy line with the bottom edge at the top of the vertical keel. Show the lapped butt forward of frame *46*, located and of width as dimensioned in the Plan of Inner-Bottom, on the plate. The *offset* of the forward plate, or the point where the plate leaves the molded line, is 9 inches forward of the forward end of the after plate. Finish the sketch by drawing the breaks in the plates and angles at the ends and showing the symbols of riveting in vertical-keel butts; then put on the lettering.

51. Next draw the Plan of Inner Bottom. At a point $7\frac{7}{8}$ inches above the bottom border line, and extending the same as the base line, draw the center line of the ship, which represents also the center line of the inner-bottom plating, and on this line, from the views previously drawn, project points locating the frame lines.

At frame *51*, mark with pencil, points 12 feet $8\frac{1}{2}$ inches on each side of the center line; also at frame *38* locate points 7 feet 6 inches each side of the center, and connect the forward points with the after ones by dot-and-dash lines to represent the knuckle, or intersection, of the molded lines of the margin and the tank-top, or inner bottom, plates. The general construction represented will be made plain by reference to the cross-section, Plate 1052.

At frame *51*, at a distance of 15 feet $4\frac{1}{2}$ inches to port of the center line, locate a point, and at frame *38* locate another point

10 feet 2 inches to port of the center line. Connect these with a full line. This line indicates the intersection of the margin plate and the shell, the margin plate being considered as swung about the knuckle into the horizontal plane, or plane of the inner bottom.

Draw the edges of the center strake of inner-bottom plating 21 inches each side of the center line; these will be dotted. Locate on the starboard side the sight edge of the strake next to the center. The sight edge is the edge of plating that is seen from the side away from the the frames, beams, or stiffeners, as explained in connection with Fig. 30 in *Ship Drafting,* Part 1; in this case it is the edge seen by a person standing on the tank top, or inner bottom.

On the port side, locate the edges of the strake next the center strake, both edges being sight edges; 9 inches aft of frame *41*, this strake widens out to the margin in order to prevent the forward edge of strake *B* from coming to a point; the butt lap at this end is 3 inches wide.

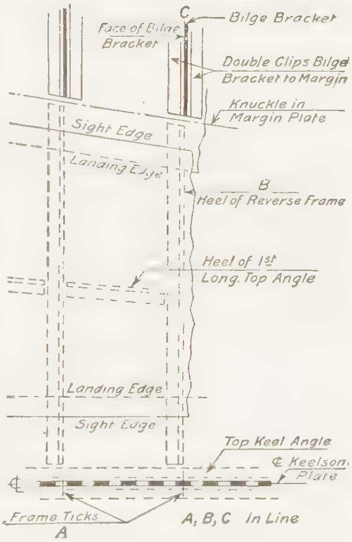


FIG. 10

Locate all butts and landing edges as shown on the plan, the landing edges being the dotted lines parallel to and near the sight edges. Beyond frames *38* and *51* and to the starboard of the center-line strake of the inner bottom, the plates are shown broken off. The starboard side shows part of the tank top with the inner-bottom plating removed.

52. Draw the vertical keelson as a heavy dotted line with the dots connected by fine solid lines. As indicated in Fig. 10, which shows a number of details to a larger scale, this is done by drawing a fine line each side of the center line and then fill-

ing the black dots between. Next show the top center-keel angles, each by two dotted lines on each side of the center-keelson plate. With the heels in line with the frame ticks that were projected from the view of the flat keel, draw the reverse frames extending from just beyond the toe of the top center-keel angles to within 2 inches of the knuckle. These reverse frames are represented by three lines, the flange being dotted throughout and the toe and heel lines being full lines on the starboard side outboard of the break in the inner-bottom plating, and dotted elsewhere.

53. From points 6 feet 4 inches each side the center line at frame *51*, to points 4 feet each side the center line at frame *38*, draw light pencil lines. These represent the molded lines of No. 1 longitudinal, or side keelson. Between the reverse frames, draw the intercostal angles connecting the side keelson to the tank top, the heels of the angles being on the molded line of the longitudinal. These intercostal angles are drawn dotted where the plating is represented to cover them and full or dotted in other parts as per instructions for drawing the reverse frames. Aft of frame *51*, just a portion of No. 1 longitudinal is shown, and also a small portion of No. 2 longitudinal 10 feet 6 inches from the center line. On the port side, draw the 4″×4″×.50″ angle connecting the margin plate and the shell.

54. In line with each of the reverse frames, draw one of the clips connecting the bilge brackets to the margin at frames *38* to *50*, inclusive. These clips extend from about 2 inches from the knuckle line to about ½ inch from the toe of the margin angle, as shown more plainly in Fig. 10. Forward of each of these clips is a bilge bracket, shown by a heavy line, and then the *doubling* clip shown by two lines. The sides of the heavy line representing the bilge bracket form the backs of these angles. As the angles are 3½ in.×3½ in. and the bracket .38 inch thick, the total length fore and aft will be 7.38 inches, but on a quarter-inch scale the scaled length may run a little over.

55. On the odd-numbered frames, *39* to *49*, inclusive, are shown the gusset plates connecting the margin-plate top flange to the flange of the bilge bracket. These brackets are usually

detailed on another plan (See Plate 1052), and are here shown just to complete the plan; so no dimensions appear. They extend forward 18 inches from a point 7 inches aft of the after edge of the bilge bracket, and the lap on the margin plate inboard of the knuckle line is 5 inches. The flange on top of the bilge bracket is 4 inches wide, and is shown dotted. The diagonal lines from the outboard end of the gusset plates to the corners of the lap on the margin complete this detail. Note that the double angles connecting the margin and bilge brackets are not shown behind the gussets, because, as will be seen by reference to Plate 1052, they are not in the same plane.

Draw the butts in the margin plate as dimensioned, making them at right angles to the landing edge at the knuckle.

56. At frame *51*, draw a heavy line with its after side coincident with the frame tick; this represents the plate of the water-tight bulkhead above the inner bottom. The vertical flange and the toe of the bounding bar to the inner bottom are shown by two solid lines aft of the plate. At the port side of the vessel the angle is shown heavy in section where it turns up over the margin angle similar to the floor bounding angle shown in Fig. 9. The toe of the top bounding angle of the water-tight floor is shown dotted just forward of the toe of the bulkhead bounding bar. Also, 13½ inches each side of the center line and two spaces of 27 inches each to port, locate the heels of bulkhead stiffener bracket clips. These are 3½-inch angles. Beyond to port is a space of 28 inches to the heel of another bracket clip, and finally 30 inches to another. The first and the last angles toe inboard; all others outboard. The object of showing these is to indicate where riveting through the tank top occurs. These clips extend from about 1½ inches from the bulkhead to the molded line of the frame next forward. This is to secure a firm connection to a solid floor instead of the flexible connection that would be afforded if the bracket were shorter and connected to the tank-top plating only.

57. Next, locate a water-tight manhole (*W. T. M.*) for access to the double-bottom compartment. The center of this manhole is 16 inches aft of frame *49*, and 9 feet from the center

line of the ship. The cut in the plate is 15 inches×18 inches and has circular ends. Draw the major axis perpendicular to the center line of the vessel and locate the centers of the end arcs, respectively, $1\frac{1}{2}$ inches inboard and outboard of the center of the manhole.

58. Midway between the No. 1 longitudinal and the knuckle on the starboard side of the drawing, draw a dot-and-dash center line, which locates a line of lightening holes in the double-bottom floors. Similarly, locate the centers of the lightening holes between the center keelson and the No. 1 longitudinal. The outer holes in floors *38* to *42*, inclusive, are 18 inches in diameter, and all others are 24 inches×18 inches, the 24 inches being the horizontal measurement. Locate the ends of the holes by fore-and-aft lines, $\frac{1}{8}$ inch (actual size) long, and draw the diagonal lines in dash. This is a symbolic way of representing the lightening holes. The riveting symbols and the lettering, as shown on the plate, complete this view.

59. The view of Longitudinal No. 1 is next to be made. At a point $1\frac{7}{16}$ inches, actual measurement, below the top border line, draw the base line, and on this, in positions projected from the plan, tick off the frames. Then 4 feet (to scale) above this, draw the molded line of the inner bottom. As this longitudinal tapers in toward the center line of the vessel as it goes forward, and as the body lines of the ship rise nearer to the center line as they approach the bow, as was shown in Plate 1051, this keelson will be of nearly constant depth throughout the part here shown. Actually the bottom line usually curves up slightly like the buttock lines in Plate 1051. To facilitate drawing, it has been assumed here that the bottom is parallel to and 12 inches above the base line. Draw a line representing the bottom. Square up from the base line, and indicate by light pencil lines the molded frame lines the full depth of the keelson. With the forward side of the flanges at these pencil lines, draw in heavy section the $3\frac{1}{2}''\times3\frac{1}{2}''\times.44''$ frames and reverse frames toeing aft. Immediately forward of these angles draw heavy lines representing the floors extending from the bottom to the top of the side keelson, or longitudinal.

Draw $3'' \times 3'' \times .40''$ clips, one forward of and one aft of each floor to connect the floors and side keelson. These clips extend from 4 inches above the bottom to 4 inches below the top of the keelson. A convenient way to draw these clips is to draw light pencil lines at distances 4 inches from the top and bottom and then draw between these pencil lines the two lines representing each clip. This view of the longitudinal is from the center looking outboard, hence the angles are all shown full.

Next draw the $3\frac{1}{2}'' \times 3\frac{1}{2}'' \times .42''$ angle clips connecting the longitudinal to the inner bottom plate and the shell. These clips extend from 4 inches aft of the face of the floor to 2 inches forward of the face of the next floor. See Detail of Longitudinal No. 1. Draw in the general view of the longitudinal the cut backs in the plates, as shown in the detail.

The keelson plates are intercostal between the floors—that is, the floors are continuous athwartships, and the keelson plates, .40 inch thick, are separate plates between the floors. In the keelson plates, in the center of each space between floors, is a $15'' \times 18''$ lightening hole. This is drawn in the same way as the manhole in the tank-top plating. The inner-bottom and shell plating may or may not be shown in this view. If shown, it would be in heavy lines, the inner-bottom above the top angle and the shell plating below the bottom angle. It is not shown here. The four views—flat plate keel, vertical keel, inner bottom, and longitudinal No. 1—should all be in line; that is, the same frames in all the views should be in one vertical line. If there were other longitudinals to be drawn, they would, if possible, be in the same line. These views should be completed by putting on the lettering as shown.

60. Next, draw the Detail of Flat Keel. Draw the center line 8 inches (actual measurement) above the bottom border line. Locate one frame line $1\frac{3}{4}$ inches from the right-hand border and tick in three more frames 30 inches (to $\frac{1}{2}$-inch scale) apart to the left. Draw the vertical keel, bottom angles, flat keel, shell strakes adjacent to keel, frames in inner bottom, and the flat-keel butt straps according to the dimensions given in Art. **46** and following, where the drawing of the flat keel was

described. Draw a light line $2\frac{1}{2}$ inches from the heel to locate the centers of the rivets in the bottom keel angles. When a line of rivets is located by measurement from the heel of an angle or the edge of a plate, the measurement is called the *outgauge* and the rivets are said to be *outgauged* a certain distance from the heel or edge, and the center line of the row of rivets is called the *outgauge line*, or the *gauge line*. The outgauge line for the frames is then drawn $1\frac{7}{8}$ inches from the heel. In the 6-inch seam, draw outgauge lines $1\frac{1}{2}$ inches from each edge, and in the $6\frac{3}{4}$-inch seam draw such lines $1\frac{11}{16}$ inches from each edge. Rivets must not be nearer the edge of a plate, butt strap, or end or toe of an angle, than one and one-half diameters. This is important to remember. In each case, the size of rivets is given in the Riveting Instructions on this plate, which are in accordance with the requirements of Lloyd's Riveting Tables already given.

Locate a rivet by a small circle 2 inches in diameter at the intersection of the rivet line of the frame and the rivet line of the bottom angles of the keel, also one at the intersection of the frame rivet line and the outer-seam rivet line. As the rivets through the frames are 1 inch in diameter, as shown by the Riveting Instructions, the end rivets in the frames must be $1\frac{1}{2}$ inches from the end and should be so located. In the three right-hand, or forward, frames locate a rivet half way between the end rivet and that in the outer row of the seam. At the left-hand, or after, frame, which has a water-tight floor and hence has water-tight rivet spacing, locate a rivet at the inner row of seam rivets and two others equally spaced between this and the rivet in the keel angle.

The rivets in this keel angle are 1 inch in diameter and must not exceed $4\frac{1}{2}$ inches in spacing. The distance, lengthwise of the ship, between the rivets already located is one frame space, or 30 inches; and 30 divided by $4\frac{1}{2}$ gives $6\frac{2}{3}$; hence, there will be six rivets or seven equal spaces of $4\frac{2}{7}$ inches between these rivets, except in way of the keel butt strap.

Locate the end of the forward keel angle 5 inches forward of the molded frame line, and make the lap 12 inches long. The taper is 11 inches long. It can be figured out that the end

rivets in the butt lap of these angles, when spaced as just described, are 1.70 inches from the after end, and 1.73 inches from the forward end of the butt, which distance is in excess of the $1\frac{1}{2}$ diameters required.

Locate, as per dimensions, the treble-riveted butt in the shell strake next the flat keel. This is seen on the port side just aft of the right-hand frame. Rivets in this seam are 1 inch in diameter (See Riveting Instructions) and the outer rows will each be $1\frac{1}{2}$ inches from the edge of the butt and the other row will be half way between. From the dimensions given, the distance from the rivet in the right-hand frame to the right-hand row in the butt lap is $12+1\frac{1}{2}-1\frac{7}{8}=11\frac{5}{8}$ inches, $1\frac{7}{8}$ inches being the outgauge of the frame rivets. According to the Riveting Instructions, the spacing of the rivets in the seam must not exceed 4 inches; then, in $11\frac{5}{8}$ inches there would be ($11\frac{5}{8} \div 3=3\frac{7}{8}$) three spaces, or two rivets, between the frame rivet and the nearest seam rivet.

The distance from the left-hand seam rivet to the outgauge line on the second frame is $9+1\frac{7}{8}+1\frac{1}{2}=12\frac{3}{8}$ inches, therefore two rivets in each seam row equally spaced $4\frac{1}{8}$ inches are provided between the left-hand rivets in the butt and the frame. This slightly exceeds the limit, but three rivets would be too closely spaced.

In the 6-inch seam clear of the butt, there will be required eight spaces, or seven rivets, between frame rivets to avoid exceeding the 4-inch spacing required by the Riveting Instructions. In the $6\frac{3}{4}$-inch seam, $1\frac{1}{8}$-inch rivets are used, and six rivets between the frames will give $4\frac{2}{7}$-inch spaces, which are less than the allowed maximum of $4\frac{1}{2}$ inches.

The treble-riveted double butt strap in the flat keel is $21\frac{1}{2}$ inches wide, as per Table I, *Ship Drafting,* Part 1, for plates .92 inch thick, the thicker plate governing the size of rivets and size of strap. From the same table, the rivets are $1\frac{1}{8}$ inches diameter. Locate the first row of holes $1\frac{1}{2}\times1\frac{1}{8}=1\frac{11}{16}$ inches from each edge of the strap. The inner rows will also be $1\frac{11}{16}$ inches from the edges of the plates, or on $3\frac{3}{8}$-inch centers. The intermediate row on each side of the strap will be equidistant from the others, or $3\frac{11}{16}$ inches. Rivets through

the seams and through the keel angles will be spaced like this in way of the straps. The rivets in the top straps are $1\frac{1}{2}$ diameters, or $1\frac{1}{16}$ inches, from the ends, and there will be one intermediate line of rivets.

61. Next, draw the Detail of Vertical Keel. Draw a straight line, representing the bottom of the keel, $2\frac{7}{16}$ inches below the top border and extending from 6 inches to within $\frac{3}{4}$ inch from the right border. The scale of the drawing is to be $\frac{1}{2}$ inch=1 foot, and the dimensions will be those given in Art **49** where the keel was first described. Four feet, to scale, above the base line, draw a straight line representing the top of the keel. Draw the $3\frac{1}{2}''\times 3\frac{1}{2}''\times .44''$ vertical angles connecting the vertical keel, or keelson, to the floors. These are on the frame lines as described in connection with the drawing of the general view. Draw the top and bottom keel bars, or angles, $3\frac{1}{2}$ in.$\times 3\frac{1}{2}$ in.$\times .50$ in. and 5 in.$\times$5 in.$\times .54$ in., respectively, as described in connection with the views already drawn. Draw the butt lap and indicate the scarfs. Note that the after end of the forward plate is a full line and the forward end of the after plate is a dotted line which shows that the forward end of the after plate is on the far side of the forward plate. Fig. 11 is a horizontal section through the vertical keel, in way of this butt lap and shows the connections of the water-tight floor and the ordinary floor.

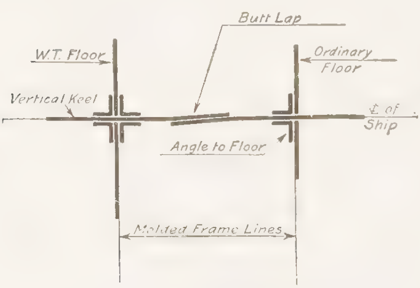


FIG. 11

The Riveting Instructions on the plate show that the rivets through the clips or angles connecting the vertical keel to the floors are to be $\frac{7}{8}$ inch in diameter and not over $4\frac{3}{8}$ inches apart. Outgauge the line of rivets $1\frac{5}{8}$ inches from the heel of each angle and locate the first rivet $1\frac{1}{2}$ diameters, or $1\frac{5}{16}$ inches, from the top end of the angle. The rivets in the two flanges of

these angles must not come opposite each other, else there will be difficulty in driving them. In order to stagger the two lines—those through the vertical keel and those through the floor—and have the same number of rivets in each, there must be a wide space between the lower end of the angle and the last rivet in the flange that connects to the keel; and opposite this space will be the lower rivet in the flange connecting to the floor, this rivet being $1\frac{1}{2}$ diameters from the end. Accordingly, make the rivet spacing $4\frac{1}{4}$ inches. These vertical angles are $48-(6+4\frac{1}{2})=37\frac{1}{2}$ inches long. After deducting $1\frac{5}{16}$ inches for the first rivet and 8 spaces of $4\frac{1}{4}$ inches each, there is left $2\frac{3}{8}$ inches from the last rivet to the lower end of the bar. Rivets in the flange to the floor are spaced the same, but from the bottom up, and hence there is proper staggering.

The bottom angle is connected to the vertical keel by $\frac{7}{8}$-inch rivets spaced not to exceed 5 diameters, or $4\frac{3}{8}$ inches. These rivets are staggered, with alternate rivets in the lower row omitted. Outgauge the two rows 2 inches and $3\frac{5}{8}$ inches, respectively, from the heel of the angle, and locate a rivet in the outer row at the intersection with the gauge line of the rivets in the vertical angles. The distance between these rivets is a frame space, 30 inches, and seven equal spaces would be $4\frac{2}{7}$ inches each, which is within the maximum allowed. Space rivets in the lower row midway between those in the upper, but omit alternate rivets. One rivet $2\frac{1}{2}$ inches above the heel of the bottom angle secures the water-tight angle on the after side of the water-tight floor.

The rivets through the top angle are spaced the same as those in the top row of the lower keel angle, but the outgauge is $1\frac{7}{8}$ inches. In the frame space forward of the water-tight floor, a rivet is located at the intersection of the gauge lines of the top angle and of the forward vertical angle on the water-tight floor. Five rivets will be located in the space between this and the rivet above the next forward vertical angle, and it will be noted that the butt comes in this space.

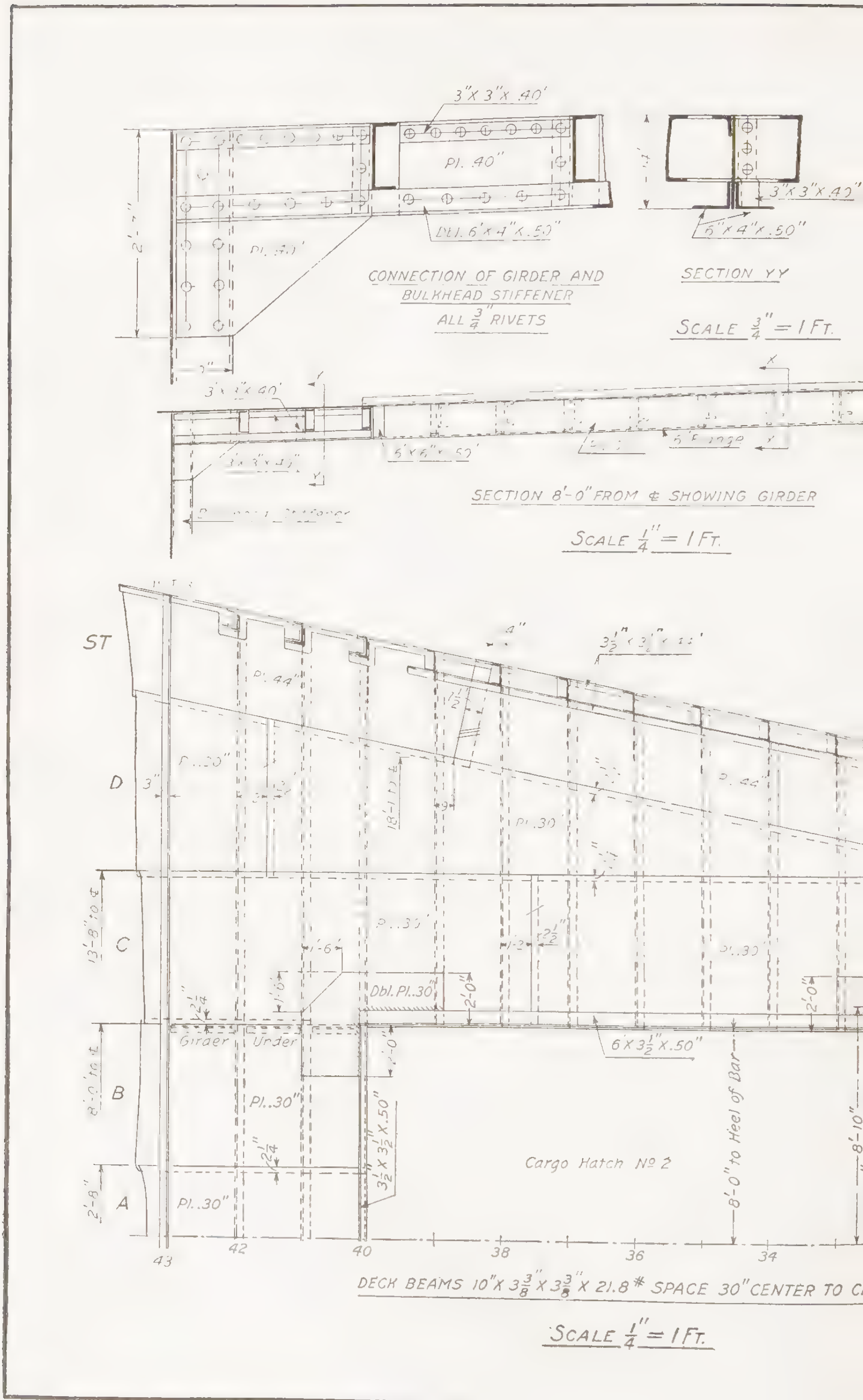
The outer rivets in the butt are $1\frac{5}{16}$ inches from the edge, and the middle row is half way between these. The distance between the rivets in the upper angle and in the top row of the

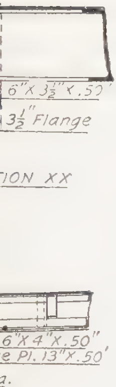
lower angle is $48-(1\frac{7}{8}+3\frac{5}{8})=42.5$ inches. This divides into 13 equal spaces of 3.27 inches each, which is less than the allowable maximum of $3\frac{1}{2}$ inches. Accordingly there will be 12 rivets in each row between the top and bottom angle.

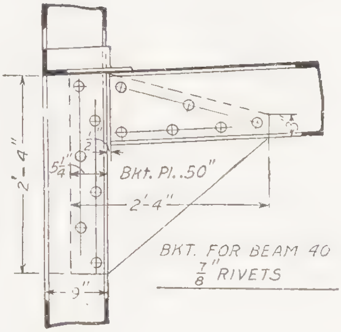
62. Next draw the Detail of Longitudinal No. 1. The base line for this is a continuation of the Detail of Vertical Keel, and the frame line is $6\frac{3}{4}$ inches from the right-hand border. Draw in pencil the bottom of the longitudinal 12 inches, to scale, above the base line, and the top 4 feet above the base line, and on these lines tick in the location of the frame. With the heels in line with the frame tick, draw in heavy section the $3\frac{1}{2}'' \times 3\frac{1}{2}''$ frame and reverse frame, and also draw the vertical $3'' \times 3''$ angle to floor, this angle extending from 4 inches above the bottom of the longitudinal to 4 inches below the top. Draw the floor as a heavy line against the vertical angle, and to the right draw the vertical angle on the forward side and of the same extent as the after one. Draw the top and bottom angles extending to within 2 inches of the forward side and 4 inches of the after side of the floor plate. The intercostal plates forward and aft of the floor are to be shown broken off. The only information given on this sketch that is not in the general view is the extent of the cut backs at the frame and reverse frames and the extent of the vertical angles. The spacing of rivets in the vertical angles is similar to that in the vertical keel in that the rivets in the two flanges must be staggered. The spacing is 7 diameters.

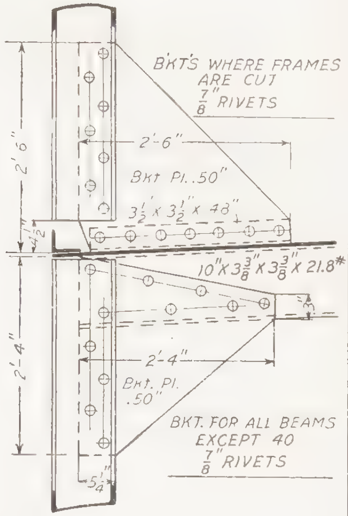
63. The details that have been shown on the plate would not necessarily come together at any one place, as in the Detail of Flat Keel, where a butt in the flat keel is shown in the next frame space to a butt in the shell and in the next space but one to a water-tight floor. Everything is put in small space in the view to show all the methods in one detail.

The floors are omitted in all drawings except the detail of the vertical keel and those of the side longitudinal. This is because they would cause more lines but would show nothing additional. The lightening holes in the floors are indicated in the plan of the inner bottom, but the floors are not shown. In


3"X 3"X .40"
Pl. .40"
Dbl. 6"X 4"X .50"
CONNECTION OF GIRDER AND
BULKHEAD STIFFENER
ALL 3/4" RIVETS
3"X 3"X .40"
6"X 4"X .50"
SECTION YY
SCALE 3/4" = 1 FT.
6"X 6"X .50"
SECTION 8'-0" FROM ℄ SHOWING GIRDER
SCALE 1/4" = 1 FT.
ST
D
C
B
A
Pl. .44"
Pl. .30"
Pl. .44"
Pl. .30"
Pl. .30"
Dbl. Pl. .30"
Girder Under
Pl. .30"
Pl. .30"
6"X 3 1/2"X .50"
3 1/2"X 3 1/2"X .50"
8'-0" to Heel of Bar
Cargo Hatch Nº 2
13'-8" to ℄
8'-0" to ℄
2'-8"
2'-0"
43
42
40
38
36
34
DECK BEAMS 10"X 3 3/8"X 3 3/8"X 21.8# SPACE 30" CENTER TO C
SCALE 1/4" = 1 FT.







SCALE 3/4" = 1 FT.

RIVETING INSTRUCTIONS

CONNECTIONS	DIA OF RIV.	SPACING DIA'S	SPACING INCH
Single Riveted Edge Laps 2¼" Wide	5/8"	4½	2¾"
Single Riveted Butt Laps 2½" Wide	5/8"	4	2½"
Deck Plating to Beams	5/8"	7	4⅜"
Single Riveted Edge Lap 2½" Wide	3/4"	4½	3⅜"
Stringer Plate Treble Riveted Butt Lap 7½"	3/4"	3½	2⅝"
Stringer Plate to Beams	3/4"	7	5¼"
Stringer Angle W.T.	3/4"	5	3¾"
Stringer Angle N.W.T.	3/4"	7	5¼"
W.T.B. Angle to Deck	3/4"	5	3¾"
Hatch Bounding Angles	7/8"	7	6⅛"
Longitudinal Angles on Girders	3/4"	7	5¼"
Edge of Dbl. Pls. to Deck	3/4"	4½	3⅜"

DECK PLAN

DRAWN BY________
DATE________

1054

the side keelson, or longitudinal, the floors are in section and as the longitudinal plates are cut at the floors it is necessary that the floors be shown. Where double angles are fitted, as at a water-tight floor, there the floor is shown.

The sides, or outer edges, of the inner bottom are shown as straight lines, whereas they would ordinarily be curved. This was done to facilitate drawing.

64. Riveting in general is completely covered by the Riveting Instructions on the plate and by the classification society's rules, and these instructions should be put on the drawing in the form shown. These two enable the templet maker in the shops to locate all rivets.

To draw the Riveting Instructions on the plate, locate a horizontal line $5\frac{1}{2}$ inches above the lower border line and extending 4 inches to the left of the right-hand border line. From the end of this horizontal line, draw a vertical line, as shown, and on it lay off one space of $\frac{3}{8}$ of an inch and 13 spaces of $\frac{3}{16}$ inch each and draw the horizontal lines as shown. One inch to the left of the right-hand border line draw the vertical column rule and divide the space between it and the border into three equal parts by vertical lines, the ruling over the two right-hand columns being arranged as shown. Then letter in the instructions as shown on the plate, putting over all the head Riveting Instructions with the single line under it, and add the note under the instructions.

Because the title of this plate is longer than usual, the lettering on it may be made $\frac{3}{16}$ inch high instead of $\frac{1}{4}$ inch as has been the practice on ordinary drawing plates. When the title and number of the plate have been put on the plate will be complete.

PLATE 1054: TITLE, DECK PLAN

65. Plate 1054 is a plan of a portion of a ship's deck showing the way a deck-plating plan is laid out and showing some of the necessary details that go with it. The plan view of the deck plating, and the section 8 feet from the center line, showing girder, are drawn to a scale of $\frac{1}{4}$ inch = 1 foot, while the details of brackets are drawn to a scale of $\frac{3}{4}$ inch = 1 foot. The

part of the deck represented is toward the bow, the after part being at the left. Begin this plan by drawing the center line of the ship parallel to and $1\frac{1}{2}$ inches above the bottom border line; then, $1\frac{1}{2}$ inches to the right of the left-hand border, draw another line perpendicular to this center line. From the intersection of these lines mark off on the center line points 30 inches apart to locate the molded frame lines; draw light pencil lines through these points perpendicular to the center line, and number them as shown.

66. In actual practice the next step would be to lay off from the center line, on these frame lines, the half breadths of the deck which are given in the book of offsets, marking the points with dots, and then draw a fair line through the dots

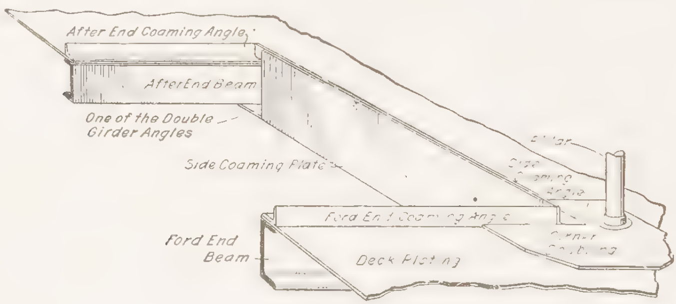


FIG. 12

on the frame lines; but on this plate the edge of the deck shown has been made a straight line for convenience in drawing. Therefore, on frame line *43*, mark a point 24 feet from the center line, and on frame line *30*, mark another point 17 feet 6 inches from the center line, and connect the two points with a straight line. This represents the intersection of the deck with the outside of the ship and is called the *molded deck line*.

67. The next step is to show any openings in the deck. Between frames *32* and *40* is a cargo hatch 16 feet wide, the general appearance of which is shown in Fig. 12. Therefore, between these two frames draw a line parallel with the center line and 8 feet from it to represent one side of the hatch opening. Next the deck-plate lines are to be laid in. The stringer

plate, which is the plate next to the outside, is always laid in first, as it has a definite width assigned on the midship-section drawing. In this case it is assumed to be 48 inches wide and .44 inch thick, so draw a dotted line parallel to the line representing the deck line, or the outer edge of the deck, and 48 inches from it, and then a full line also parallel to the dotted line and $2\frac{1}{2}$ inches farther outboard. These lines show the seam, the full line representing the sight edge, and the dotted line the landing edge. The sight edges of the remainder of the deck plating are now drawn, parallel to the center line, at 2 feet 8 inches, 8 feet, and 13 feet 8 inches, respectively, from it. At a distance of 1 foot 6 inches forward of frame *32*, strake *C* widens out to the stringer plate, in order to prevent the forward edge of strake *D* from coming to a point, the butt lap at this place being $2\frac{1}{2}$ inches wide. The landing edges are drawn dotted $2\frac{1}{4}$ inches from the sight edges and parallel to them as shown.

68. Now, in their places at the outboard edge of the deck, draw the sections of the frames, which are $9'' \times 3\frac{1}{2}''$ channels. The back of the web is in line with the frame tick on the center line, and the flanges are parallel to the deck line, the outer flange having its side coincident with that line. Indicate the cuts in the stringer plate about the frames. These are 4 inches wide and 9 inches deep. The frames toe aft or to the left. One-half inch forward of the frames, draw the deck beams dotted. They are represented by three lines, the two to the left indicating the web and the one to the right, $3\frac{3}{8}$ inches from the left-hand line, indicating the toe of the beam. At frame *40* the beam is reversed and its heel is in line with the back of the frame. On the forward side of frame *40* and between the frames and beams elsewhere, indicate by heavy dotted lines the deck-beam brackets extending 2 feet 4 inches inboard from a point $5\frac{1}{4}$ inches outboard of the inner flange of the frame. See detail at upper right-hand corner of the plate.

Next draw the doubling plates at hatch corners as dimensioned. Doublings are usually placed at the corners of all

hatches in steel decks within the middle half-length of the vessel, to strengthen the deck at these points.

Draw the butt laps in strakes *C*, *D*, and *S T* as dimensioned, those in *S T* being perpendicular to the sight edge. When the deck line is curved, the sight edge at the stringer seam is straight and the change in direction of the sight edge is made at the stringer butt.

69. In actual practice the connection of the stringer plate to the shell would be of one type for most of the length of the ship, but on the plate are shown three different types of connections that occur frequently.

The type called stapling, shown on frames *40* to *43*, is used over a water tank when the frames are not cut at the deck. The details of stapling were shown in Fig. 33, *Ship Drafting*, Part 1.

The type shown at frames *30* to *32* is used when the deck is water- or oil-tight and the frames are cut and bracketed at the deck, this condition occurring, of course, only where the shell and frames continue above the deck shown.

The third type, shown at frames *33* to *39*, is used on a deck of a cargo steamer when over a cargo hold. The outside angles are called *shell clips* and the inner continuous angle the *stringer angle*. The space between the two angles is filled with a wooden block set in cement or with a mixture of coke and cement.

Draw the shell clips and stringer angle, and the stapling. It will be noticed on frames *30* to *32* that there are clips shown on top of the deck stringer over the beams. These clips are $3\frac{1}{2}$ in. $\times 3\frac{1}{2}$ in. $\times .48$ in. and are 2 feet $4\frac{1}{4}$ inches long. The outer end is $5\frac{1}{2}$ inches from the deck line. The construction is shown in the upper right-hand detail, which also shows the frame continuing above the deck. The placing of these clips over the beams is good practice when the deck is water-tight, but in case of an oil-tight deck they should be on the near side of the bracket so as not to produce three-ply riveting. By three-ply riveting is meant riveting through three thicknesses of material.

70. Having finished the stringer angles, next draw the bulkhead bounding angle at frame *43*, on top of the plating. The stringer angle is continuous under this angle in order to make a good water-tight connection and the angle is shown in heavy section where carried up the side.

At 8 feet from the center line is a girder under the deck, placed to support the beams and also to form the side of the hatch. This girder is supported by a pillar at frame *32*. Beyond the hatch opening at each end, draw dotted the clips connecting the girder to the deck, with the heels of the clips 8 feet from the center line, and then show the pillar foot on top of the doubling plate. This pillar is 8.62 inches outside diameter and has a $3\frac{1}{2}$-inch flange connecting it to the deck. Cross-hatch the edges of the doublers at the corners of the hatch to show that the doublers do not run under the hatch bounding angles. Note that the seam lap between strakes *B* and *C* is cut out under the doubling plates and that the doubling plates act as seam straps. This is done to make a flush surface under the doublers.

71. Draw the $6'' \times 3\frac{1}{2}'' \times .50''$ bounding bar, or coaming angle, of the hatch with the 6-inch flange to the deck and extending between the toes of the end beams. The heel is 8 feet from the center line. The end coaming angles, $3\frac{1}{2}$ in. $\times 3\frac{1}{2}$ in. $\times .50$ in., have their toes at the heels of the deck beams under; that is, the toes of both face the hatch. Draw another line parallel to and about $\frac{1}{2}$ inch inboard of the side coaming angle. This line represents the plate coaming, the general construction of which was shown in Fig. 5.

When the lettering and dimensions have been put on, this view will be complete.

72. The next view to show is an elevation of the girder; this is shown just above the deck plan. From a point $3\frac{3}{4}$ inches below the top border line and $1\frac{1}{2}$ inches to the right of the left-hand border line, draw a straight line to a point $3\frac{7}{16}$ inches below the top border line and 10 inches from the left-hand border line. This represents the molded line of the deck, which has a sheer, or rise, forward. Now draw another line parallel

to and 14 inches below the deck line. This is the bottom of the girder, the depth of the girder being determined by the depth of the deck beam (10 inches) plus the girder angle (4 inches). Next, draw, in pencil only, another line parallel to the molded deck line and 10 inches below it, to locate the bottoms of the beams. Then, project up the beam lines from the plan view below, and draw in the sections of the deck beams that are not cut, as shown, the beams being 10 inches$\times 3\frac{3}{8}$ inches.

Draw the $6'' \times 4'' \times .50''$ angles at the bottom of those parts of the girder plate not in the way of the hatch. In these parts the deck beams are shown to pass through the girder plate, 4-inch cuts being made for the purpose clear across the plate, as indicated by the dotted lines showing the cut continuing behind the bottom angle.

On top of the molded deck line draw a heavy line to represent the deck plating in section, making the line dotted in way of the hatch frames *32* to *40*, as shown.

Show the 9-inch stiffener at bulkhead *43*, and the bracket 2 feet 7 inches deep, which connects the stiffener to the girder and makes the stiffener act as a support for the end of the girder. See details in upper left-hand corner of the plate. Between frames *32* and *40* the girder plate also forms the side of the hatch, constituting the hatch coaming, and has a 6-inch flange on the bottom for strength and to keep the cargo lifting ropes from chafing. Draw a dotted line $\frac{1}{2}$ inch above the bottom of the girder, in way of the hatch only, to represent this flange. The deck beams where cut, as *33* to *39*, are connected to the girder or hatch coaming by a $6'' \times 3\frac{1}{2}''$ angle, as shown in Section *X X*, with the $3\frac{1}{2}$-inch leg of the angle against the girder plate. Draw these connections to the girder dotted as shown. To make the arrangement plainer, the ends of the beams have also been dotted in. Show the $6'' \times 6''$ corner angles at beams *32* and *40*. Next draw $3'' \times 3'' \times .40''$ angle clips that connect the deck to the girder plate, and then the $3'' \times 3'' \times .40''$ clips connecting the through beams to the girder plate.

Above the deck plating draw the hatch angle $3\frac{1}{2}$ inches high extending from the toe of beam *32* to the toe of beam *40*, and then draw the section lines *X X*. The arrows indicate which

way the section itself is seen. The pillars above and below the deck now remain to be shown. These are 8.62 inches and 10.75 inches, outside diameter, respectively, and are connected to the deck and the bottom of the girder by a $6'' \times 3\frac{1}{2}''$ angle ring, the 6-inch flange being against the pillars.

73. The next step is to show the enlarged details of some of the parts so as to make the riveting clear. The detail in the upper left-hand corner of the plate shows the connection of the girder to the bulkhead stiffener, and also shows the general scheme of riveting for the girder angles. To draw this, begin at a point $1\frac{1}{8}$ inches below the top border line of the plate and $1\frac{1}{2}$ inches to the right of the left-hand border line and draw a straight line parallel to the deck line of the girder below and extending about 4 inches to the right. This represents the top side of the girder. Then, to the scale of $\frac{3}{4}$ inch = 1 foot, draw another line parallel to the first and 14 inches below it to form the bottom of the girder. The remainder of the detail is similar to the girder below, but at $\frac{3}{4}$ inch to the foot instead of $\frac{1}{4}$ inch to the foot. After finishing the main outline, draw the rivet line in the top angle $1\frac{3}{4}$ inches down from the heel of the 3-inch angle and parallel to it. The rivet line in the bottom angle is $2\frac{1}{2}$ inches up from the heel of the angle, and the rivet lines in the vertical clips to the beams are $1\frac{5}{8}$ inches from their heels. The rivet lines in the channel are 2 inches in from its edges, the reason for the increased dimension being that the fillet in a channel is larger than in an angle, and more room must be allowed in order that the rivet head may lie flat on the web of the channel. To represent the rivets, put in the circles $1\frac{1}{4}$ inches in diameter, as shown, placing those next to the plate edges $1\frac{1}{4}$ inches back from the edge and equally spacing the others.

74. The next view to the right is a view looking aft, showing a transverse section of the girder, as at *Y Y*, and the clip connecting it to the deck beam. Draw first the vertical girder plate $6\frac{3}{4}$ inches from the left-hand border line, 14 inches deep (to scale), then draw the beam 10 inches deep at right angles to it. Then show the $6'' \times 4''$ angles at the bottom, and

the 3″×3″ clip, dotted behind the beam and joggled over the 6″×4″ angle. After this, draw the vertical rivet line $1\frac{5}{8}$ inches from the heel of the 3″×3″ angle and show the two end rivets, of the same diameter as before, 2 inches from the bottom and the top of the beam and the third one in the middle.

75. The view marked *Section X X* is a transverse section through the girder in way of the hatch, and is drawn to show the connection of the beam to the girder plate and also to the 6-inch flange of the girder.

First draw the deck line 1 inch below and parallel to the top border line of the plate, and make the section of the hatch girder plate $8\frac{7}{8}$ inches from the left-hand border line. The section of the girder plate should be $\frac{1}{2}$ inch thick with a 6-inch flange at the bottom. Next draw the deck beam, which is a channel 10 inches deep, and draw the 6″×$3\frac{1}{2}$″ angle clip dotted behind the beam and flanged $3\frac{1}{2}$ inches at the bottom. The rivet lines in the 6-inch flange of the clip are $2\frac{1}{4}$ inches and $4\frac{1}{2}$ inches, respectively, from the heel of the angle. The end rivets on the inner row are 2 inches from the top and the bottom edges of the channel and the third rivet is midway between. The two rivets in the outer row should be spaced equidistant from those on the inner row. The three short lines drawn across the section of the girder indicate the rivets in the $3\frac{1}{2}$-inch leg of the clip. The two upper rivets are spaced opposite to the two in the outer row, while the third is up 3 inches from the bottom of the girder flange. There are also two rivets indicated through the $3\frac{1}{2}$-inch flange at the bottom of the clip. These are in line with the rivet lines above. Now show the thickness of the deck plating by a solid heavy line and then draw the 6″×$3\frac{1}{2}$″×.50″ angle above, connecting the deck to the girder plate.

76. The detail in the upper right-hand corner is to show the beam brackets attached to the frames and also the frame bracket above the deck when the frames are cut at the deck.

In drawing this, first draw the 9-inch channel frame, as shown, with the heel $2\frac{5}{8}$ inches from the right-hand border of the plate, and the molded line of the deck intersecting the heel

of the frame at a point $2\frac{3}{4}$ inches below the top border line. Then draw in pencil the molded line of the deck so that it will meet the right-hand border line $2\frac{9}{16}$ inches down from the top. On this line draw the deck plating. The drawing is to be to a scale of $\frac{3}{4}$ inch=1 foot.

Dot in the 10-inch channel beam under the deck and then draw the bracket that supports it. Show the $3\frac{1}{2}$-inch stringer angle in section above the deck and then draw the top bracket with the dotted $3\frac{1}{2}'' \times 3\frac{1}{2}'' \times .48''$ angle clip connecting it to the deck. This clip extends to within 1 inch of the toe of the stringer angle, this clearance being allowed for caulking the stringer angle. Draw the two lines of rivets connecting the brackets to the frames, one line $1\frac{1}{2}$ inches in from the edge of the bracket plate and the other $1\frac{7}{8}$ inches from the heel of the channel frame. The rivet line in the $3\frac{1}{2}$-inch angle is 2 inches from the heel of the angle. The lines of rivets that attach the lower bracket to the beam are $1\frac{1}{2}$ inches down from the edge of the bracket plate and parallel to it and $1\frac{7}{8}$ inches up from the bottom of the beam and parallel to the beam. The end rivets are in each case spaced $1\frac{1}{2}$ inches from the edge of the plate or shape, and the intermediate rivets are equally spaced as shown. Use a $1\frac{1}{2}$-inch circle to indicate the rivet heads.

77. The other beam bracket to the left shows the type of connection used on a reverse beam, as at frame *40*. The procedure of drawing is similar to the beam bracket just described. The frame is located $6\frac{1}{16}$ inches from the right-hand border line and the molded line of the deck intersects the frame $2\frac{3}{4}$ inches down from the top border line. Draw the deck line at the same angle as in the last detail. The procedure is similar to that used in drawing the other, except that the beam faces the same way as the frame and there is a $\frac{1}{2}$-inch space between the frame and the end of the beam. The frame is shown continuous and the stringer angle stapled.

78. Now draw the table of Riveting Instructions. Make the top line $6\frac{1}{2}$ inches up from the base line and make it 4 inches long. In other respects the procedure is similar to that

described for Plate 1053. The plate is then finished by putting on all dimensions and lettering as shown, together with the title and the number of the plate.

PLATE 1055: TITLE, TRANSVERSE BULKHEAD

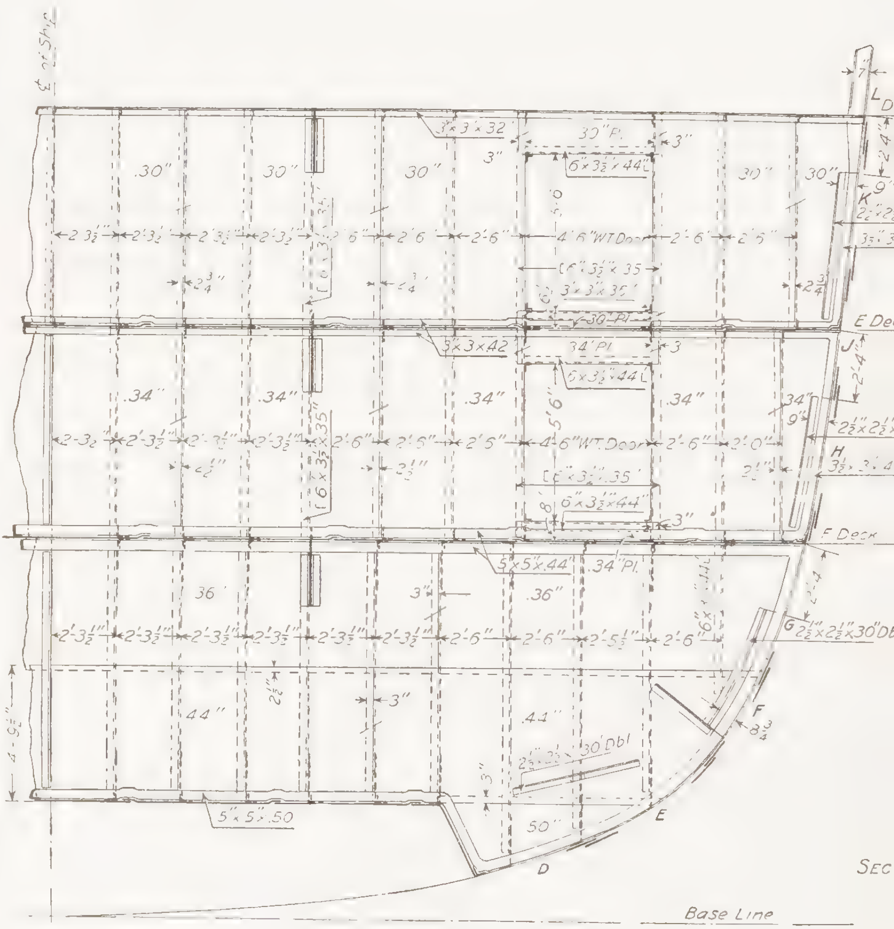
79. A transverse bulkhead is a division wall extending across the ship and separating compartments. The principal bulkheads are water-tight and extend to the uppermost continuous deck or to the deck below that one. If there are intermediate decks they are continuous through the bulkhead. Likewise the inner bottom is continuous in way of—that is, under—bulkheads. Bulkheads are always located on a frame. Some vessels have longitudinal bulkheads.

Bulkheads are made of plates and are stiffened by channel bars, bulb angles, or plain angles, that run vertically or horizontally about 30 inches apart. Bulkheads are attached to the shell, decks, and inner bottoms by single or double angles; if single angles are used they are on the side opposite the stiffeners. These stiffeners are usually bracketed or otherwise attached to the decks and inner bottoms. Water-tight bulkheads must be strong enough to withstand the pressure due to one adjacent compartment being filled with water to the height of the load water-line. All seams and butts and the edges of bounding bars must be caulked. Doors in water-tight bulkheads must be water-tight.

In the foreground of Fig. 13 is shown part of a transverse bulkhead similar in many respects to that to be drawn in Plate 1055. The stiffeners and the brackets to the deck both above and below are plainly seen, as well as the deck beams, deck plating, and general construction.

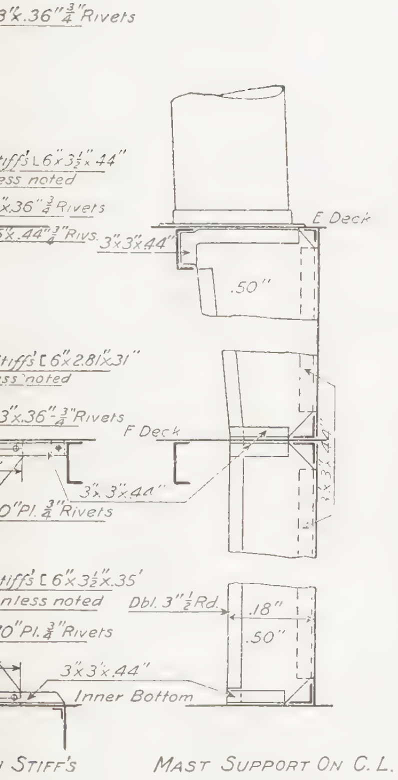
80. To draw the bulkhead shown on Plate 1055 first draw the base line of the vessel $1\frac{3}{4}$ inches (actual measurement) above the lower border of the plate, and the center line of the vessel $\frac{5}{8}$ inch from the left-hand border line. The drawing is to be made to a scale of $\frac{1}{4}$ inch=1 foot.

Lightly draw in pencil water-lines 2 feet apart, from a point 2 feet above the base line to 26 feet above the base line. Draw



WATER-TIGHT BULKHEAD 50
STARBOARD SIDE LOOKING FORWARD

SCALE $\frac{1}{4}'' = 1$ FT



STIFF'S MAST SUPPORT ON C. L.

SCALE $\frac{1}{2}'' = 1$ FT.

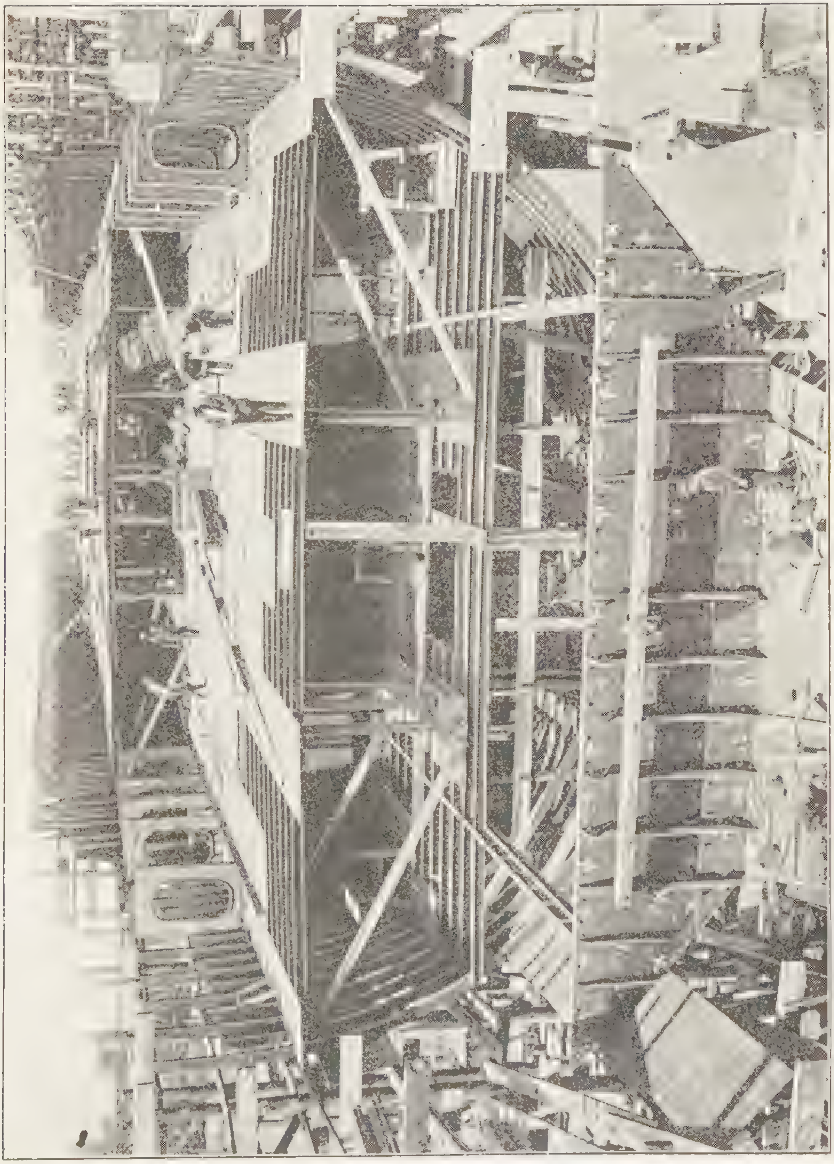
RIVETING INSTRUCTIONS

Connection	Dia of Rivet	Spacing	
		Dia's	In-
W.T. Seams & Butts of Plating	$\frac{3}{4}''$	$4\frac{1}{2}$	$3\frac{3}{8}''$
W.T. Bounding L's 5"x5" Zig Zag Rivets	$\frac{3}{4}''$	5	$3\frac{3}{4}''$
W.T. Bounding L's to Plating Sing. Riv	$\frac{3}{4}''$	$4\frac{1}{2}$	$3\frac{3}{8}''$
Bracketed Stiff's to Plating	$\frac{3}{4}''$	7	$5\frac{1}{4}''$
Lugged Stiff's (For 15% of Stiff. Length from Ends)	$\frac{3}{4}''$	4	3"
Lugged Stiff's (Middle of Stiff.)	$\frac{3}{4}''$	7	$5\frac{1}{4}$
Mast Support Pl'tg to L's & ½ Rd	$\frac{3}{4}''$	7	$5\frac{1}{4}$
All Other Connections Not Shown or Noted	$\frac{3}{4}$	7	$5\frac{1}{4}$

TRANSVERSE BULKHEAD

DRAWN BY ___________
DATE ___________

1055



also a water-line 1 foot above the base line. Draw buttocks 4 feet apart, from the center line to 20 feet from the center line. The layout of these lines is similar to the layout of the cross-section in Plate 1052 and in Fig. 2. Lay off the 6-inch half siding to the right of the center line.

81. The accompanying Table of Offsets for Transverse Bulkhead will define the shape of this bulkhead. Note that the decks are here designated by letters. The half width of *D* deck is given in the table of water-lines but the height at which that half width is laid off is taken from the table of deck heights. The dimensions, as is the custom, are given in feet, inches, and eighths of an inch.

TABLE OF OFFSETS FOR TRANSVERSE BULKHEAD

Water-Lines	Half Widths		Deck Heights At Side	Deck Heights At Center
1′	12–6–6	*F* Deck	13–3–4	13–3–4
2′	16–7–0	*E* Deck	20–9–3	20–9–3
4′	21–2–3	*D* Deck	28–3–4	28–6–2
6′	23–3–5			
8′	24–7–0			
10′	25–6–0	Buttocks	Heights	
12′	26–2–0	4–0	0– 2–1	
14′	26–7–5	8–0	0– 5–6	
16′	27–0–0	12–0	0–11–2	
18′	27–3–7	16–0	1– 9–6	
20′	27–7–0	20–0	3– 3–6	
22′	27–9–6			
24′	28–0–0			
26′	28–3–0			
D Deck	28–5–7			

82. Draw a light pencil line 4–0–0 above the base line. This is the molded line of the inner bottom. The outer face of the margin plate is its molded line, and the point where the molded line of the margin cuts the molded line of the inner bottom extended is the **inner trace** of the margin; the point where the molded line of the margin plate cuts the molded frame line is the **outer trace** of the margin. In this case the

outer trace is 15–0–0 from the center line and the inner trace 13–9–0 from the center line.

83. It will be seen from the Table of Offsets that *F* and *E* decks have no camber and that in the half beam 28–5–7 of *D* deck there is only 28–6–2 less 28–3–4 equals 0–2–6 camber. As a curve representing such a small camber is hardly distinguishable when drawn to the scale of this drawing, the deck line may in this case be drawn as a straight line parallel to the base line. If the scale were larger it would be permissible to put in that deck line with a ship curve, making the tangent to the deck line at the center line of the vessel parallel to the base line.

84. Having located the half breadths and buttock points according to the distances given in the table, draw by means of ship curves a fair line through them. This is the molded line of the side of the ship and is similar to the molded line of the midship section that was drawn in Plate 1052. Draw the molded margin line between the two traces; then the space within the *D* deck line, molded side line, margin line, and inner bottom is the extent of the bulkhead.

85. Next locate, according to the accompanying Table of Offsets for Plating, the sight edges between the margin and *D* deck. The figures are for the projection of the sight edge on the molded frame line, the capital letters referring to the strakes.

TABLE OF OFFSETS FOR PLATING

STRAKE	DISTANCE FROM CENTER LINE	HEIGHT ABOVE BASE LINE
Lower *E*	18–9–4	2– 9–5
Upper *E*	23–3–0	5–10–7
Upper *F*	25–1–0	9– 0–5
Lower *H*		13–10–5
Upper *H*		18–10–4
Lower *K*		22– 6–5
Upper *K*		27– 5–0

The terms *upper* and *lower* refer to the upper and lower edges of the strakes. Where upper and lower are used for the

same strakes, as in *E, H,* and *K,* an outside strake of an in-and-out system is designated. In the case of *F,* where only one sight edge is designated, the strake is a *clinker* strake, as illustrated in Fig. 31, *Ship Drafting,* Part 1. The seams are all $5\frac{1}{4}$ inches wide and are of course under the out strakes.

Having located the sight edges, locate the seams and draw in place about 15 inches of each plate as a heavy line.

86. The sight edges of the inner-bottom plates, beginning with that nearest the center line of the vessel, are distant from the center line as follows: 2 feet 6 inches, 8 feet $1\frac{1}{2}$ inches, and 13 feet 1 inch. The center strake and margin seams are $5\frac{1}{4}$ inches wide and the other seam is $2\frac{1}{2}$ inches wide. All seams are joggled, the center-line strake being an in strake (as seen from the top), the next strake an out, the third a clinker, and the margin an in strake.

87. The sight edges of *F* deck, beginning with that nearest the center line, are distant from the center line 3 feet 6 inches, 10 feet 2 inches, 16 feet 2 inches, and 22 feet 9 inches, and all seams are $2\frac{1}{2}$ inches wide. The center strake is an out strake, the next a clinker, the next an in, next out, and the stringer is an in strake. Seams are all joggled.

The sight edges of *E* deck, beginning with that nearest the center line, are distant from the center line 3 feet 6 inches, 10 feet 2 inches, 16 feet 2 inches, and 23 feet 11 inches, all seams being $2\frac{1}{2}$ inches wide. The strakes are the same as on *F* deck and seams are joggled.

88. Draw the margin angle and stringer angles with their heels on the molded frame line. Next draw the bounding bars, showing the joggle over all inner-bottom and deck seams. At the shell, the bounding bar is drawn with its heel on the molded line. The shell bounding bars when marked $3\frac{1}{2}'' \times 3''$ have the $3\frac{1}{2}$-inch flange to the shell and the 3-inch flange to the bulkhead; $\frac{7}{8}$-inch rivets are used through the shell and $\frac{3}{4}$-inch through the bulkhead. Show the 7-inch channel frame projecting down through *D* deck. The inner flange is cut off, and from the deck to a point 2 feet 4 inches below, the web tapers from 7 inches wide to 3 inches, the same as the angle bounding

bar below. The angle bounding bar under *D* deck is joggled around the cut channel and is shown in heavy section at the corner.

Frequently there is a web frame in the 'tween-decks space over a bulkhead. Web frames consist of a plate from 1 to 3 feet deep, are attached to the shell by an angle, and have a half-round or angle on the inner edge.

89. In the previous Section, under the head of Details, it was explained that in the forward part of the ship the frame flanges toe aft and that in the after part they toe forward, and the same is true in regard to bulkhead bounding bars. Therefore, as the plate shows a view of a forward bulkhead as it appears to a person looking toward the bow, the bounding bars toe aft. Draw as a full line the bulkhead-plating sight edge extending outboard from the top of the inner-bottom plating, and 3 inches above it draw the landing edge dotted. Similarly, 4 feet 9½ inches above the inner bottom, draw the sight edge with the landing edge 2½ inches below it. These seams are joggled so that the stiffeners, which are on the forward side, may be flush against both the upper and the lower plates.

90. Next locate the heels, or molded lines, of the stiffeners. One is on the center line and the others are located at the intervals shown on the plate. Note that the stiffeners on the outboard side of the door opening toe outboard and that the others toe inboard. All stiffeners except the two lower on the center line are indicated by three dotted lines as shown, the two lines near together representing the web of a channel or the outstanding flange of an angle and the one line representing the other flange or flanges of the angle or channel. The sections to the right of this view show that below *E* deck the stiffeners are channels and that between *D* and *E* decks angles are used.

The center-line stiffeners between *E* deck and the inner bottom form the mast support and will be described later.

In the section at the right of the main view it will be noted that the stiffeners between *D* and *E* decks and *E* and *F* decks

have clips or angle lugs at top and bottom attaching them to the decks. In the main view show these angles in heavy dot lines on the side of the web of the channel stiffener and the outstanding flange of the angle stiffeners, except at the tops of the fourth stiffeners from the center line at *D* and *E* decks. At these points the stiffeners are supported by brackets to the longitudinal deck girders and therefore no angle lugs are necessary.

At the heads of the channel stiffeners below *F* deck, except the fourth from the center line, and at the foot of all on the inner bottom, show, by heavy dotted lines, brackets 21 inches deep. These brackets are connected to the deck and to the inner bottom by clips, also shown in heavy dotted lines. The outboard stiffener below *F* deck, being short, is not so heavy or strong as the others, being a $6'' \times 3\frac{1}{2}'' \times .44''$ angle with an angle lug at the top and no connection at the bottom. This stiffener extends downwards from *F* deck to a point 1 foot 8 inches above the molded side line. Other hold stiffeners, or those between *F* deck and the inner bottom, end at the bounding bar.

The three stiffeners inboard of the short outboard one just mentioned are connected to the shell at their bottoms by flanged brackets toeing inboard to avoid closed bevels. These brackets are shown in heavy dotted lines. Note that the angle clips on the lower-hold stiffener brackets at the top of the seventh and bottom of the first stiffener from the center are reversed, or toe inboard. This is done to clear the adjacent seam in the plating, the brackets being so located that the seam rivets could not take the bracket clips. Where there is nothing to prevent, however, as at the head of the second stiffener from the shell, under *E* deck, the seam rivets extend clear through and hold the lug.

Indicate the single-riveted, vertical lap butts in the two lower courses of plating. These laps are 3 inches wide and the landing edges are on line with the toes of the channels. By so locating butts on stiffeners, a line of rivets is saved, the stiffener rivets are closer spaced to conform to the water-tight requirements.

91. Between *E* and *F* decks, locate $2\frac{1}{2}$-inch single-riveted butt laps on the second and fifth stiffeners from the center and on the outboard stiffener. Similarly locate vertical lap butts $2\frac{3}{4}$ inches wide between *D* and *E* decks. The inner plates extend to the toe of the stiffener flange and the laps are measured from this point. In the case of the $6'' \times 2.81''$ channels, the outgauge of the rivet line in the flange of the stiffener will allow of the standard width of lap. In the upper 'tween-decks space (spaces between decks are called 'tween-decks) the stiffener flanges are $3\frac{1}{2}$ inches wide and the outgauge is $1\frac{7}{8}$ inches from the heel. This leaves $1\frac{5}{8}$ inches from the toe, and as the center of the rivets must not be nearer the edge of the plate than one and one-half diameters, the width of the lap will be $1\frac{5}{8}+(1\frac{1}{2}\times\frac{3}{4})=2\frac{3}{4}$ inches, $\frac{3}{4}$-inch rivets being used.

The bulkhead plates in the 'tween-decks spaces are not joggled. At the plate butt, the outer plate is set or sprung back and a wedge filler, similar to that at *h* and *j* in Fig. 30, *Ship Drafting,* Part 1, is inserted between this outer plate and the bounding angle, which is straight.

92. Eight inches above the top of *F* deck beams and $6\frac{1}{2}$ inches above the top of *E* deck beam and parallel to the base line, draw full lines between the stiffeners at the water-tight doors. These lines represent the heel of a $6'' \times 3\frac{1}{2}'' \times .44''$ angle on the far side of the bulkhead having the short flange against the bulkhead. At a distance of 5 feet 6 inches above these angles draw similar angles parallel to the base line and toeing upwards. Between these horizontal angles the heels of the vertical stiffeners forming the sides of the door openings should be solid, as there being no covering shown over the doors all sides can be seen. The heels of these stiffeners are also sight edges.

At the corners of the doors draw in heavy section the $3'' \times 3'' \times .36''$ angle clips; then draw the two dotted lines that complete the view of each horizontal angle. Above and below each door is a horizontal plate lapping 3 inches on the plates at the sides of the doors, which come flush to the heel of the $6'' \times 3\frac{1}{2}''$ channel stiffeners. With the center line of the $\frac{3}{4}$-inch

rivets $1\frac{1}{8}$ inches from the plate edge, a $1\frac{7}{8}$-inch outgauge on the channels is allowed.

93. In line with the fourth stiffener from the center line and at each deck, is a girder under the deck beams. The brackets connecting this girder to the bulkhead are shown as heavy lines extending down 27 inches from the molded deck line. The inboard faces of these brackets coincide with the outboard face of the web of these stiffeners. On each side of the brackets are $3'' \times 3''$ angle clips extending from the lower edge to about an inch below the toe of the bulkhead bounding angle. As these would be detailed on the girder drawing their size is not given here.

Extend the bulkhead plates and bounding angles a little to the left of the center line and show the breaks.

94. On the molded frame line at a point 6 feet $5\frac{1}{2}$ inches above the base is the molded line, or heel, of the bilge stringer angle, though the angle is not shown here. Mark this point, as from it is to be drawn the bracket connecting the bilge stringer to the bulkhead. The position of this bracket is determined by first locating a point 25 feet 8 inches above the base line at the center line of the ship and drawing a light line connecting this point with the point just marked on the bilge. On this line the bilge bracket is drawn as a heavy line extending 3 feet inboard from the shell. On the under side of the bracket, show a $3'' \times 3''$ angle extending from the inner edge of the bracket to within an inch of the bounding angle. The bracket would be detailed on the stringer drawing and therefore is not shown in detail here. This bracket is usually nearly perpendicular to the shell plating.

95. The bilge ceiling and the cargo battens are supported by $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times .30''$ angles on each side of the bulkhead. The line of the bilge ceiling is from the intersection of the margin and tank-top molded lines to a point on the molded frame line 6 feet $5\frac{1}{2}$ inches above the base line. Draw this line in light pencil. The heels of the angle supports for the bilge ceiling are on this line. The angles are 4 feet 6 inches long and the inboard ends are 2 feet 8 inches from the intersection of the

margin and the tank-top molded lines. Draw the angle on the near side of the bulkhead in full lines and note with dots that the angle on the far side is cut for the channel bulkhead stiffener.

The cargo-batten supports are $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times .30''$ double angles parallel to the molded side line, and in the 'tween-decks spaces they are 9 inches, or the depth of the frames, from the molded lines. In the hold, or space between *F* deck and the inner bottom, the angle toes inboard and as the face or inside of the outstanding flange is 9 inches from the molded line, the dimension to the heel is $8\frac{3}{4}$ inches. The angles extend from the lower bounding bar or from the bilge stringer bracket to 2 feet 4 inches below the deck above. The reason for reversing the hold angle is to make it possible to caulk the toe of the $5'' \times 5''$ bounding angle. The angles are marked double on account of their being on both sides of the bulkhead.

96. The two figures at the right of the main view are sections through the bulkhead. The first, or left-hand, one is a general section showing the ordinary stiffeners, and the right-hand section shows the web support for the mast.

At a distance of $8\frac{1}{2}$ inches from the right-hand border line draw a light vertical line in pencil to represent the molded line of the bulkhead, and from the elevation drawing project over to this view the inner-bottom plate. This sectional view will be drawn to a $\frac{1}{2}$-inch scale and the plate and stiffeners are to be shown broken off between the end connections of the stiffeners to the decks and inner bottom. Project over the deck plating and draw it in heavy lines. Show the floor and the reverse frame below the inner bottom, and show also the end section of the $9'' \times 3\frac{1}{2}''$ channel deck beam at *F* deck 30 inches forward of the bulkhead. Between *D* and *E* decks and between *E* and *F* decks draw the stiffeners of the sizes indicated and extending from deck plate to deck plate. In the hold, below *F* deck, the stiffeners extend only to the toes of the upper and the lower bounding angles. At the top and bottom of the upper stiffener show the $3'' \times 3'' \times .36''$ angle clips to the deck plating. The gauge line for the rivets is $1\frac{3}{4}$ inches

from the heel, and the rivets, which are $\frac{3}{4}$-inch, are $1\frac{1}{4}$ inches from the ends. The clips are $5\frac{5}{8}$ inches long, one end being flush with the toe of the $6'' \times 3\frac{1}{2}'' \times .44''$ angle stiffener.

97. The $6'' \times 2.81''$ channel stiffeners in the lower 'tween-decks are connected to the *E*-deck plates by $5'' \times 5'' \times .44''$ angles, $5\frac{5}{8}$ inches long. The top row of rivets is outgauged $1\frac{7}{8}$ inches from the heels and the lower rivet $3\frac{3}{4}$ inches. Rivets in the top row are $1\frac{3}{8}$ inches from the ends of the angle and the lower rivet is equidistant from the two end rivets. At the foot of the $6'' \times 2.81''$ channel stiffeners there is a $5'' \times 3'' \times .36''$ angle clip extending $3\frac{1}{2}$ inches to the right of the channel and $5\frac{5}{8}$ inches to the left of the right-hand edge. The rivets through the stiffener are the same as for the clip at the top of this stiffener. The vertical leg of the clip is cut off diagonally, the flange to the deck being made longer to get a rivet farther from the bulkhead plate.

98. The brackets at the head and feet of the hold stiffeners extend 21 inches from the deck and from the inner bottom, and lap on the stiffener $5\frac{1}{4}$ inches. They are 20 inches long. The angle connecting the bracket to *F* deck extends from the left-hand edge of the bracket to the deck beam forward, to which it is attached by a $3'' \times 3'' \times .44''$ angle clip with a rivet in the center of each leg outgauged $1\frac{7}{8}$ inches from the heel. The lower bracket is connected to the inner bottom by a $3'' \times 3'' \times .44''$ angle that extends from the left end of the bracket to the heel of the reverse frame on the nearest floor forward. Rivets are located $1\frac{1}{8}$ inches from each end of the bracket and three equally spaced rivets are located between. Rivets in the stiffeners are gauged $1\frac{7}{8}$ inches from the heel; the end rivets in the right-hand row are $1\frac{1}{8}$ inches from the ends of the bracket or channel and one is located between. The two rivets in the left-hand row are equidistant from the others.

99. For the mast support, draw a light vertical pencil line $5\frac{1}{16}$ inches from the right-hand border. Project over the inner-bottom plating and *E* and *F* deck plating as heavy lines. Draw the bulkhead plating as a heavy line in line with the pencil line

just mentioned. Draw the bounding bars in heavy section at the inner bottom and at *E* and *F* decks. Also draw in *F* deck beam 30 inches to the left of, or aft of, the bulkhead. At *E* deck, 18 inches to the left of, or aft of, the transverse bulkhead, locate a point representing the center line of the mast, which is 24 inches in diameter and has a slope aft of $\frac{1}{2}$ inch per foot. Through the center of the mast at *E* deck, draw in pencil a line perpendicular to the base line. Six feet above *E* deck, locate a point 3 inches to the left of this line. The center line of the mast can be drawn in pencil through this point and the center point of the mast at *E* deck. Show the mast extending above *E* deck as indicated and broken at the upper end.

The mast sides will be shown as full lines parallel to the center line of the mast. Show the $3\frac{1}{2}'' \times 3\frac{1}{2}''$ bounding angle encircling the foot of the mast at the deck.

Between the inner bottom and *F* deck there is a .50-inch web plate 18 inches wide and having the top and bottom corners at the bulkhead cut diagonally to clear the $5'' \times 5''$ bulkhead bounding angles. Between these cuts show dotted the $3'' \times 3'' \times .44''$ connecting angle to the bulkhead. Show the $3'' \times 3'' \times .44''$ angles at the bottom and top; these angles are single and are on the near side only.

Between *F* and *E* decks the web increases from 18 inches wide at *F* deck to 26 inches at *E* deck. At the beam, the plating is extended to the left into the bosom of the channel, and connection is made by means of the $3'' \times 3'' \times .44''$ angle joggled around the top of the channel beam. Show dotted the $3'' \times 3'' \times .44''$ angle connecting the web to the bulkhead plate. Also show the angle at the bottom of the web at *F* deck. Show the corner cuts in the plate.

From the lower flange of *E* deck-beam, downwards, the outstanding edge of the web plate has a 3-inch half round on each side. Show the one on the near side cut at the connecting angles and extending between them. The half round on the far side, as indicated by the dots, extends to the plating of the deck and the inner bottom, being cut, of course, at *F* deck.

100. Next put on all the lettering, add the Riveting Instructions, as shown, in the same manner as described for previous plates, and finish by putting on the title and number of the plate.

DESCRIPTION OF CARGO BOOM AND RIGGING

101. Plates 1056 and 1057, which are to be drawn next, show drawings of a cargo boom and rigging details, and as the details are parts of the one piece of apparatus they are all listed and numbered together in Plate 1057. Before taking up the drawing of them, a description of the purpose and use of the various parts will be given. In this description references will be made to the various numbered pieces that are shown on one or the other of the plates. The drawing of each plate will, however, be described separately.

102. Practically all general-cargo ships are equipped with some sort of gear for handling cargo between docks and the ship's cargo spaces. Some vessels built for special trade, as for carrying coal or ore, depend on shore facilities for loading and unloading. In such cases the appliances are of a special kind and usually complicated and expensive, as great rapidity is frequently attained. With ore-unloading facilities as found at some of the Great Lakes ports, 10,000 tons may be removed from one ship in about 10 hours. This machinery is too heavy and too expensive to install on a single ship, as it would be used only once on a voyage, whereas on shore it suffices for several vessels and may be used as fast as vessels arrive and discharge. The same applies to the loading facilities at the loading port.

The general cargo carrier, however, does not have its cargo handled so fast, and as its load is of various kinds and the ship must be loaded and unloaded at many different ports, it is absolutely essential that it carry its own cargo-handling gear. The gear usually adopted consists of cargo booms, or derricks, on the mast; these are so arranged that they can swing over the hatches, or deck openings through which the cargo is

raised from or lowered to the cargo spaces, and can also swing over the ship's side so that cargo can be handled to or from the dock or lighters that may be tied alongside. This gear is

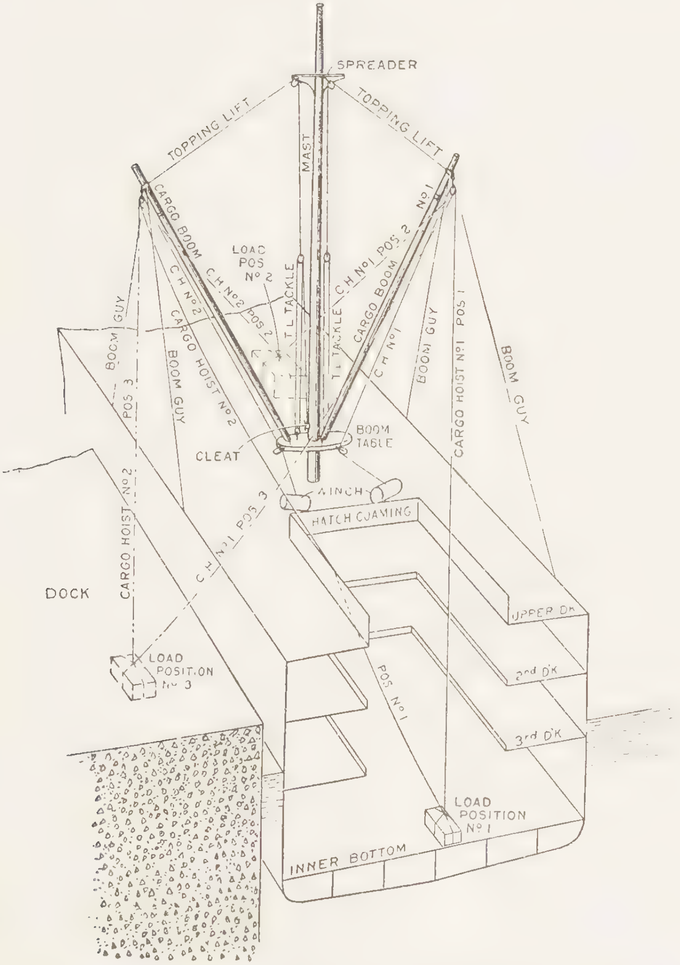


Fig. 14

illustrated in Fig. 14, which shows in a diagrammatical way the method of handling a load from the vessel's hold to the dock.

103. Cargo boom No. 1 is located over the hatch and No. 2 is swung out over the dock. They are held up by wire-rope topping lifts and manila topping-lift tackles, thus enabling the booms to be raised and lowered. The booms are kept from swinging by two vangs, or guys, to each boom, which are made fast at two fairly well separated places on the deck. Thus, the upper or free end of the boom is the apex of a triangle and cannot move.

The cargo hoists in their simplest forms have single wire or manila ropes running over single blocks to the hoisting winch located on the upper deck, so that the operator has a view down the hatch. For lifting more than $2\frac{1}{2}$ or 3 tons, the number of parts of this hoist are increased by the use of double or treble blocks. Ships are sometimes provided with special booms for lifting heavy loads up to about 50 tons and special heavy gear is provided. As this is seldom used, it is usually stowed instead of carried in the working position where it is exposed to the weather.

104. In the case illustrated in Fig. 14, both hoisting ropes are attached to the load in the hold of the ship and both winches begin hoisting together, the starboard winch, which is attached to hoist No. 1, doing most of the work in the beginning, the port winch attached to hoist No. 2 merely taking up the slack of its hoisting rope. When the load is raised clear of the hatch, the weight is gradually taken up by hoist No. 2, till the load is held in position No. 2 and is carried jointly by the two booms. Gradually hoist rope No. 2 is hauled in and hoist rope No. 1 is let out until the load is carried entirely by No. 2 and hangs directly over the dock. When lowered on the dock, as in position No. 3, hoist rope No. 1 is slack. The winches are so arranged that one operator controls the entire handling.

105. In the following description the various parts are identified by the piece numbers given in the material list on Plate 1057, each view being numbered accordingly on the plates. Cargo booms are made of wood, steel tubing, or steel plate rolled to a circular section. The boom, piece **1**, which is

drawn on Plate 1057, is of tubing. At its inner, or fixed, end there is a gooseneck casting, piece **2**, projecting into and riveted to the boom, and whose eye is attached to a swivel, piece **4**, by the swivel pin, piece **6**. The swivel is really a forked pin having a large shoulder and setting in the boom table. The boom swings vertically on the swivel pin and the boom and pin swing horizontally by the swivel turning in its seat. The swivel pin is kept in place by the locking pin, piece **7**, in the $\frac{9}{16}$-inch-diameter hole. Split pins, piece **8**, in each end of the locking pin prevent it from falling out. The bearing surfaces of the swivel should be large enough so that the frictional resistance will not be excessive.

At the upper end of the boom is the cap, piece **3**, which simply closes the end.

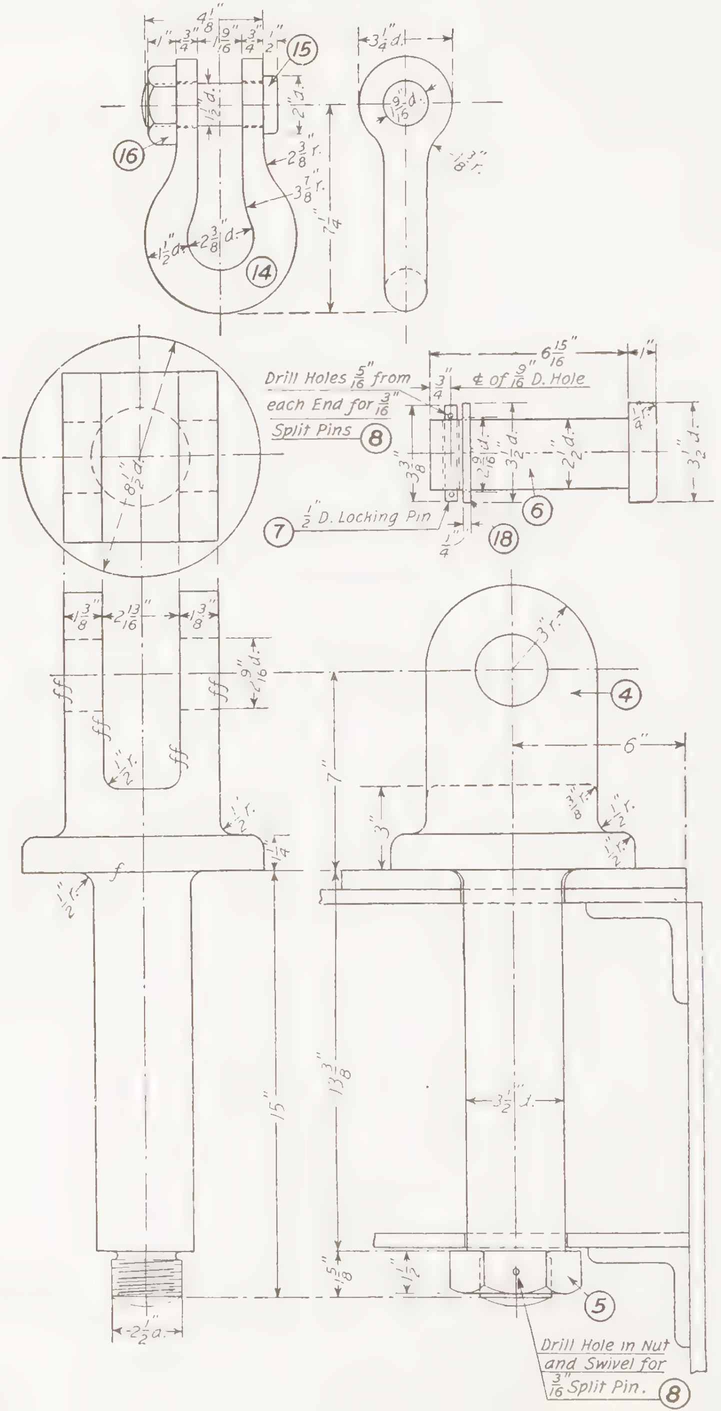
106. The topping lift is attached to the boom by means of a band, piece **9**. A shackle, piece **14**, which is like a link of a chain with one end of the link portable so that another link can be fastened in it, is attached to the end of the wire-rope topping lift. The shackle pin, or portable end, piece **15**, passes through the $1\frac{9}{16}$-inch-diameter hole in the lug on the top side of piece **9**. This lug when secured in place will be on the upper side of the boom. The band is heated and put over the end of the boom down to its proper position, $20\frac{1}{2}$ inches from the end. As it cools, it shrinks and grips the boom. To prevent any possible turning, it is also held by four $\frac{7}{8}$-inch tap rivets. The link, piece **10**, forged into the eye at the under side of the band, takes a shackle on the cargo-hoist block. A second band, piece **12**, 4 feet $1\frac{1}{2}$ inches below the first, has a lug and link for securing any additional arrangement of topping lift and cargo hoist that may be required when heavier loads are to be handled. The boom guys are attached by means of shackles to the links, piece **11**, one on each side of the upper band, piece **9**.

The cleat, piece **17**, is used to secure the free end of a rope, as that of the topping-lift tackle, shown in Fig. 14.

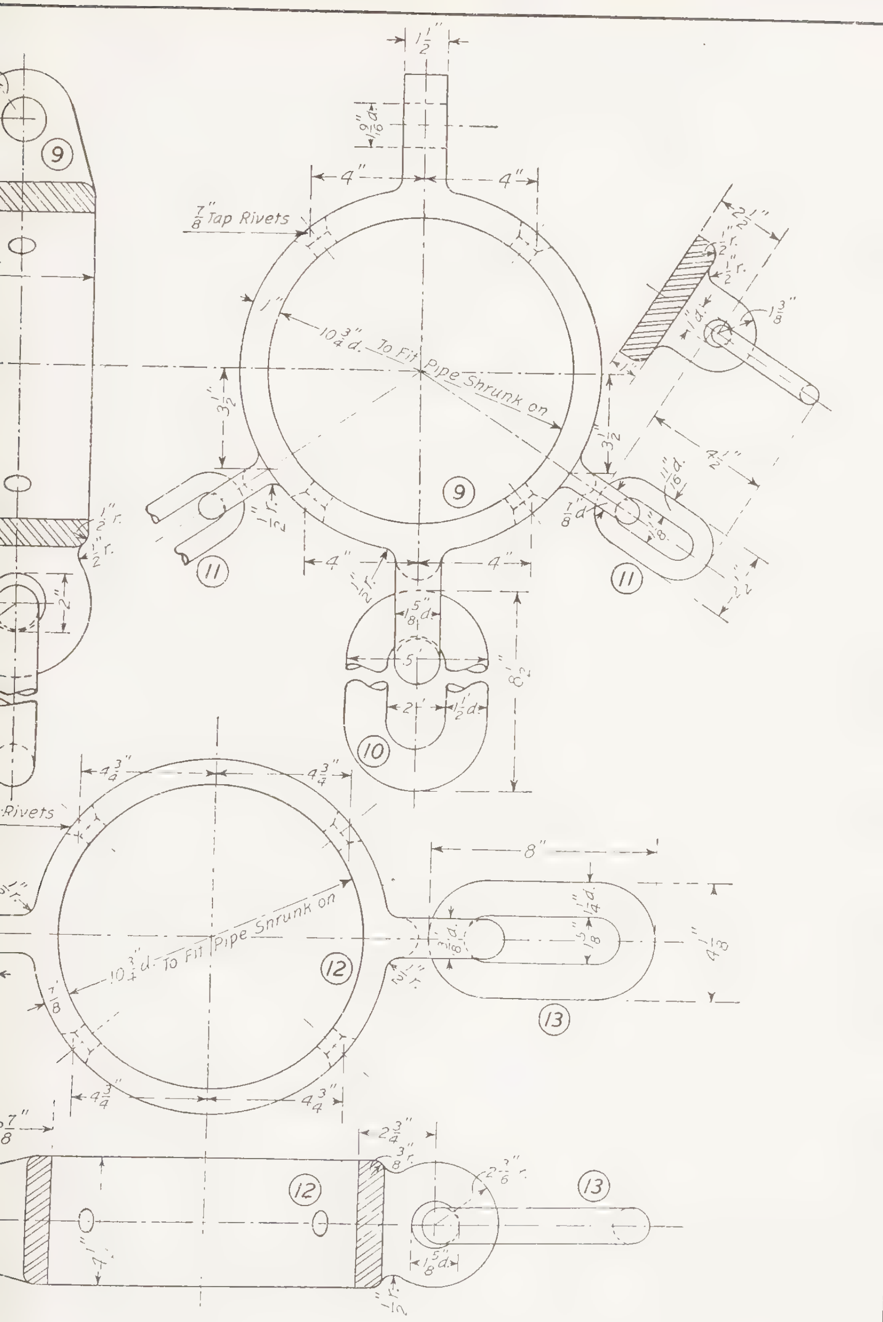
PLATE 1056: TITLE, RIGGING DETAILS

107. Plate 1056 contains details of the two boom bands, a shackle, shackle pin, gooseneck swivel, and swivel pin, mentioned in the preceding description. The first view to be drawn on this plate is a front elevation of a shackle, shackle pin, and nut, pieces **14, 15,** and **16,** and a side elevation of the shackle. The scale of this plate is to be 3 inches=1 foot.

Draw first the shackle and shackle pin. The axis of the pin is parallel to and $1\frac{1}{2}$ inches actual distance, from the top border. The vertical center line of the front elevation is parallel to and 3 inches from the left-hand border, and the center line of the side elevation is $4\frac{5}{8}$ inches from the left-hand border. In the front elevation, first locate the sides of the opening in the shackle; this opening is $1\frac{9}{16}$ inches wide and the sides are distant $\frac{25}{32}$ inch each side of the center line. Locate the outer sides of the shackle head; these are $\frac{3}{4}$ inch from the inner sides. Locate the outer face of the nut, piece **16,** 1 inch deep, the end of the parallel part of the shackle pin $4\frac{1}{8}$ inches from the outer face of the right-hand side of the shackle, and the top or outer face of the shackle-pin head, $\frac{1}{2}$ inch thick. From the table of sizes of bolts (given in *Mechanical Drawing*) it is seen that the diameter of the circumscribing circle for a hexagon nut for a $1\frac{1}{2}$-inch bolt is $2\frac{3}{4}$ inches. Draw the nut in the conventional way. Then draw the front elevation of the sides of the shackle extending from the bottom of the nut to the top; as the head of the shackle is $3\frac{1}{4}$ inches in diameter, its sides extend $1\frac{5}{8}$ inches above the center line of the shackle pin. Connect the top of each pair of these lines. Extend the inside lines of the shackle side to $2\frac{3}{4}$ inches below the center line of the pin; the outside lines extend, as before mentioned, $1\frac{3}{8}$ inches below the center line of the pin. The bottom of the shackle is of circular cross-section $1\frac{1}{2}$ inches in diameter and has a circular opening $2\frac{3}{8}$ inches in diameter. Draw in pencil the outside and inside, making complete circles $5\frac{3}{8}$ inches and $2\frac{3}{8}$ inches in diameter, the lowest point of the outside being $7\frac{1}{4}$ inches below the center line of the



Drill Holes 5/16" from each End for 3/16" Split Pins
8
℄ of 9/16" D. Hole
1/2" D. Locking Pin
7
6
18
15
16
14
4
5
Drill Hole in Nut and Swivel for 3/16" Split Pin.
8



RIGGING DETAILS

DRAWN BY ________

DATE ________

1056

pin. Connect the inside circle and the inside straight side of the shackle head with an arc of a circle of $3\frac{5}{8}$-inch radius and tangent to both. Similarly, connect the outside circle and straight sides by arcs of $2\frac{3}{8}$-inch radius. By straight dotted lines in the two sides of the head, show the hole $1\frac{9}{16}$ inches in diameter.

Draw the shackle pin, piece **15**, dotted through the shackle head and nut and full elsewhere. This is $1\frac{1}{2}$ inches in diameter from under the head to $\frac{1}{16}$ inch beyond the nut; the rounded end beyond this is drawn with an arc of a circle of $1\frac{1}{2}$-inch radius having its center on the center line of the pin. Draw the head of the pin 2 inches in diameter and having its outer edge rounded freehand.

The side elevation is drawn by first making a circle $1\frac{9}{16}$ inches in diameter, to represent the shackle-pin hole, and another $3\frac{1}{4}$ inches in diameter for the outside of the head. Draw a circle at the bottom $1\frac{1}{2}$ inches in diameter, the lower half full and the upper half dotted, with its lowest point $7\frac{1}{4}$ inches below the center line of the pin. Draw straight vertical lines tangent to the sides of this circle, and connect these to the $3\frac{1}{4}$-inch-diameter circle by arcs of circles of $1\frac{3}{8}$-inch radius and tangent to both.

108. On this drawing, the radii of the different arcs are given, as would be necessary for making the dies if the pieces were to be drop forged. Where pieces are to be hand forged and the exact shape of the particular part is not essential, it is not customary to put on the radii of all the arcs; and where such radii are not given it will be understood that the drawing indicates the general shape only, and that the blacksmith need not adhere strictly to any set dimensions, as such exactness would be difficult and unnecessary.

109. Next draw the outer boom band, piece **9**, with its horizontal axis $3\frac{1}{4}$ inches, actual distance, from the top border. The vertical axis of the front elevation is $4\frac{1}{4}$ inches from the right-hand border and the vertical axis of the sectional side elevation is $7\frac{3}{4}$ inches.

With the intersection of the horizontal and the right-hand vertical axes as a center, draw circles $12\frac{3}{4}$ inches and $10\frac{3}{4}$ inches in diameter. The inner circle is complete, but the outer one is discontinued in way of the lug at the top and of the eye at the bottom. Locate the centers of the four $\frac{7}{8}$-inch tap rivets on the outer circle 4 inches from the vertical axis. Draw the axes of these rivets as parts of radii of the circles and draw the cylindrical part of each hole $\frac{7}{8}$ inch in diameter for the inner half-depth of the band. Show the shoulder of the countersink perpendicular to the axis, and draw the countersink making an angle of 30° with the axis. All the above-mentioned lines should be dotted.

At the top, draw the lug extending to 5 inches above the inner circle—see dimensions in the end elevation. This lug is $1\frac{1}{2}$ inches thick and is connected to the outside of the band, or the outer circle, by fillets of $\frac{1}{2}$-inch radius. Show the hole in the lug $1\frac{9}{16}$ inches in diameter and having its center $3\frac{1}{4}$ inches from the inside of the band.

At a distance of $2\frac{1}{2}$ inches each side of the left-hand vertical axis, draw straight lines parallel to this axis to represent the sides of the band. Between these lines, both above and below the horizontal axis draw parallel lines at distances of $5\frac{3}{8}$ and $6\frac{3}{8}$ inches from it to indicate the inside and the outside diameters of the band. The lines indicating the outside diameter are then connected to the sides with fillets of $\frac{1}{2}$-inch radii. When the part between the vertical lines and each pair of horizontal lines is cross-hatched to represent cast steel, a typical, or conventional, section through the band is shown. Strictly speaking, a section at the top and bottom would include the lug and eye, but the way adopted is the conventional method generally used. The distinction between a **lug** and an **eye** is that the sides of the lug are flat surfaces and thus any hole through it will be cylindrical; whereas, an eye can be likened to a wire of large diameter formed into a ring and welded to the main part, as at the lower part of the boom band in this case. Such a ring may be set off from the band some distance and the space between may be solid metal.

Next, project over the rivet holes on the center of the band and show these as ellipses. The top lug is tapered, terminating in an arc of $1\frac{3}{4}$-inch radius having its center at the center of the hole, which in turn is $3\frac{1}{4}$ inches from the inner side of the band. This hole, $1\frac{9}{16}$ inches in diameter, is for the topping-lift shackle pin, piece **15**. The sides of the lug are tangent to the $\frac{1}{2}$-inch-radius rounded edges of the band and to the $1\frac{3}{4}$-inch-radius arc that forms the end of the lug.

110. At the bottom of the band is an eye that takes the block for the cargo hoist. This eye has its center 3 inches from the inside of the band and has a $2\frac{5}{8}$-inch outside radius. The outside of the eye is connected to the band by an arc of $\frac{1}{2}$-inch radius tangent to the edges of the band. The hole in the eye is 2 inches in diameter. In the front elevation this is shown by two parallel lines $\frac{13}{16}$ inch each side of the axis and connected to the outside of the band by fillets of $\frac{1}{2}$-inch radius. From dimensions on the side elevation, locate the lowest part of the eye $5\frac{3}{8}$ inches from the inside of the band, and through this point draw a circle $1\frac{5}{8}$ inches in diameter with its center on the axis. The bottom half of the circle is full and forms the lower part of the projection of the eye. The top part of the circle is dotted and represents the inside of the eye. Two inches above this circle is the bottom of a dotted arc $1\frac{5}{8}$ inches in diameter and having its center on the axis. The lower circle, half full and half dotted, and the upper dotted arc, show that the sides of the 2-inch-diameter hole are rounded.

In this eye is welded a link, piece **10**, which is $8\frac{1}{2}$ inches long and 5 inches wide, but which cannot be shown full length on the plate on account of lack of space. The lowest part of the link is $2\frac{3}{4}$ inches (actual distance) below the inside of the band. This link has a wire diameter of $1\frac{1}{2}$ inches. By **wire diameter** is meant the diameter of the rod of which the link is made. With the center on the axis and 1 inch, to scale, below the lower inside of the eye, draw a half circle of 1-inch radius. With the same center, draw the outside of the link with a $2\frac{1}{2}$-inch radius. These arcs will be dotted behind the

eye. Draw the lower part of the link with arcs of the same radii as those of the upper part, making the center on the axis and $2\frac{1}{2}$ inches, to scale, above the lowest point of the link. Draw the inside and the outside of the link tangent to the small and large arcs, but broken as shown. Project this link onto the end elevation by drawing two circles $1\frac{1}{2}$ inches in diameter —the diameter of the link wire—one tangent to the lowest inside point of the eye and the other through the lowest point of the link, $2\frac{3}{8}$ inches (actual distance) below the inside of the band. The centers of the circles are on the vertical axis. Draw vertical lines tangent to the circles and show the break as in the front elevation. The eye is dotted behind the link and the inner part of the link is dotted where hidden by the outer part.

111. Situated $3\frac{1}{2}$ inches below the horizontal axis, with their axes extending out radially through points on the outside of the band, are two eyes with links, pieces **11,** welded into them. These links take the boom guys, one being carried forward and the other aft of the boom to keep it from swinging. Although of different dimensions, these eyes and links are drawn in the same manner as the cargo-hoist eye and link just described. The necessary dimensions are given on the plate.

The section of the band and the end view of the link are drawn at the right of the front elevation. The axis is $1\frac{3}{4}$ inches, actual distance, from, and parallel to, the radial axis in the main view. The cross-hatched portion is 5 inches wide, the width of the band, and is centered on the axis. This section is 1 inch thick, and is of the same dimensions as that on the front sectional elevation. The inside of the band, or the left-hand edge of the section, is on a line perpendicular to the radial axis of the eye in the main view and extending through the intersection of this radial axis and the inside of the band. When these two links and the sectional view are drawn the sketch of the outer boom band is completed.

112. The inner boom band, piece **12,** and the link, piece **13,** are similar to the band already drawn, and are shown in front and side elevation in a like manner. The

vertical axis is 6 inches from the right-hand border. The horizontal axes are $2\frac{3}{8}$ inches and $4\frac{7}{8}$ inches above the lower border. On the boom, the band is mounted with the lug on the top and the eye and link on the bottom. In drawing it is necessary on account of space to draw the band turned quarter way around.

113. The next detail to be drawn is that of the swivel and swivel pin. A front elevation, a side elevation, and a plan of the swivel are shown, and a side elevation of the swivel pin. The side elevation of the swivel includes some of the structural part of the boom table.

At a point $7\frac{1}{16}$ inches, actual measurement, from the left-hand border, draw the vertical molded line of the $3\frac{1}{2}'' \times 3\frac{1}{2}'' \times \frac{1}{2}''$ angles. Draw the two angles with the top of the horizontal flanges $1\frac{1}{2}$ inches and $4\frac{1}{2}$ inches above the lower border. The radius of the toe and the bosom is $\frac{3}{8}$ inch.

Then, extending downwards from the heel of the top angle to a point $\frac{3}{8}$ inch from the lower border, draw a plate $\frac{9}{16}$ inch thick, to scale, broken off at the lower end; on top of the upper angle draw a plate $\frac{1}{2}$ inch thick extending about 13 inches to the left from the heel of the angle and on top of the lower angle a similar plate extending about 11 inches to the left. Show the ends broken. On top of the upper plate is a doubling plate $\frac{3}{4}$ inch thick and 12 inches wide, its right edge flush with the heel of the angle. With their centers 6 inches from the heels of the angles are holes $3\frac{9}{16}$ inches in diameter cut in all three plates. The top of the upper hole is rounded off with an arc of $\frac{1}{2}$-inch radius. As the structural work is only shown to give the relation of other parts to it, it is not shown cross-hatched and is not dimensioned. Behind the swivel the plates are dotted.

114. Draw the vertical axis of the swivel, piece **4**, for the side elevation, 6 inches, to scale, to the left of the heel of the angle. The shank of this swivel is $3\frac{1}{2}$ inches in diameter extending down $13\frac{3}{8}$ inches from the shoulder, which is at the top of the upper plates. This shank is connected to the shoulder, or head, by a fillet of $\frac{1}{2}$-inch radius. Below the

$3\frac{1}{2}$-inch diameter is a threaded portion of the swivel $1\frac{5}{8}$ inches long and $2\frac{1}{2}$ inches in diameter, and below this the end of the swivel is rounded off with an arc of $2\frac{1}{2}$-inch radius, the center of course being on the center line of the swivel. The threading stops $\frac{1}{2}$ inch short of the shoulder. This is best shown in the front elevation described later.

The nut, piece **5**, securing the swivel in the boom table is not standard, being $1\frac{1}{2}$ inches deep and $4\frac{5}{8}$ inches over-all diameter, instead of $4\frac{15}{16}$ inches as shown in the table of bolt sizes for a $2\frac{1}{2}$-inch diameter bolt. The nut, however, is drawn in the conventional way. The split pin, piece **8**, keeps the nut from backing off.

It will be seen that the swivel has a $\frac{1}{16}$-inch clearance in the holes and that it has an allowance of $\frac{1}{8}$ inch for possible vertical motions, as the distance between the top of the $\frac{3}{4}$-inch doubling plate and the bottom of the lower $\frac{1}{2}$-inch plate is $13\frac{1}{4}$ inches.

The shoulder above the shank is $8\frac{1}{2}$ inches in diameter (see plan above the front elevation) and $1\frac{1}{4}$ inches thick. The edges are rounded off with a $\frac{1}{2}$-inch radius. Draw the elevation of this shoulder. With the center 7 inches above the bottom of the shoulder and on the center line, draw a semicircle with a radius of 3 inches. Draw tangents to this semicircle parallel to the axis and connect them to the top of the shoulder by fillets of $\frac{1}{2}$-inch radii. Draw a dotted line parallel to and 3 inches above the bottom of the shoulder, connecting this to the vertical lines by arcs of $\frac{3}{8}$-inch radii. This view now shows the side of the cheeks supporting the swivel pin, and the bottom of the slot between the two cheeks in which the end of the gooseneck, piece **2**, turns up and down. With the same center as that of the arc, draw a circle $2\frac{9}{16}$ inches in diameter which is the end elevation of the hole through which the swivel pin, piece **6**, supporting piece **2**, passes.

115. Draw a center line for the front elevation $2\frac{5}{16}$ inches (actual measurement) from the left-hand border. The elevation of the shank is the same as before and the threaded projection is shown without the nut, the number of threads being four to the inch. The lower end is also rounded off in the

same way as in the other view. Draw the elevation of the shoulder the same as in the side elevation. Project the top and center lines from the other view. Locate the inside surfaces of the cheeks $2\frac{13}{16}$ inches apart equally distant from the axis; that is, $1\frac{13}{32}$ inches each side. The cheeks are $1\frac{3}{8}$ inches wide. The bottom of the slot between the cheeks is 3 inches above the shoulder. Draw the vertical lines from the top $1\frac{13}{32}$ inches each side of the axis and show the fillet of $\frac{1}{2}$-inch radius connecting the sides and bottom. Draw the top and the outer faces of the cheeks vertical and connecting to the top of the shoulder by fillets of $\frac{1}{2}$-inch radii. By dotted lines show the $2\frac{9}{16}$-inch-diameter holes in the two cheeks.

116. For the plan view, draw the transverse axis of the swivel $8\frac{7}{16}$ inches above the lower border. Draw the longitudinal axis of the swivel in line with the vertical axis below. With the intersection of these axes as a center, draw a circle $8\frac{1}{2}$ inches in diameter, to scale, representing the shoulder which rests on the top plates of the boom table. Another circle $3\frac{1}{2}$ inches in diameter and dotted represents the shank. The cheeks are shown 6 inches wide extending equally each side of the transverse axis (above and below in this drawing). They are $1\frac{3}{8}$ inches thick and $2\frac{13}{16}$ inches apart, being $1\frac{13}{32}$ inches each side of the longitudinal axis. Show the swivel-pin holes dotted. The full lines connecting the ends of the two cheeks show the bottom of the slot between.

117. In line with the transverse axis of the swivel in the plan view, draw the center line of the swivel pin, piece **6.** Locate the end of the pin $4\frac{13}{16}$ inches from the border. Draw the pin $6\frac{15}{16}$ inches long, to scale, and its head 1 inch long and $3\frac{1}{2}$ inches in diameter. In a case of this sort where the object is round, one view with dimensions marked *diameter* is sufficient. Draw the locking pin, piece **7,** $\frac{1}{2}$ inch in diameter, in the $\frac{9}{16}$-inch-diameter hole whose center is $\frac{3}{4}$ inch from the end. As the difference in diameter is only $\frac{1}{16}$ inch, the lines should be separated a greater distance to avoid confusion. The locking pin is $3\frac{3}{8}$ inches long, and has a hole for a $\frac{3}{16}$-inch split pin $\frac{5}{16}$ inch from each end. The top of the split pin will rest on

the swivel pin, so the top will be $\frac{5}{16}$ inch + one-half the diameter of the split pin, or $\frac{13}{32}$ inch, above the top side of the swivel pin.

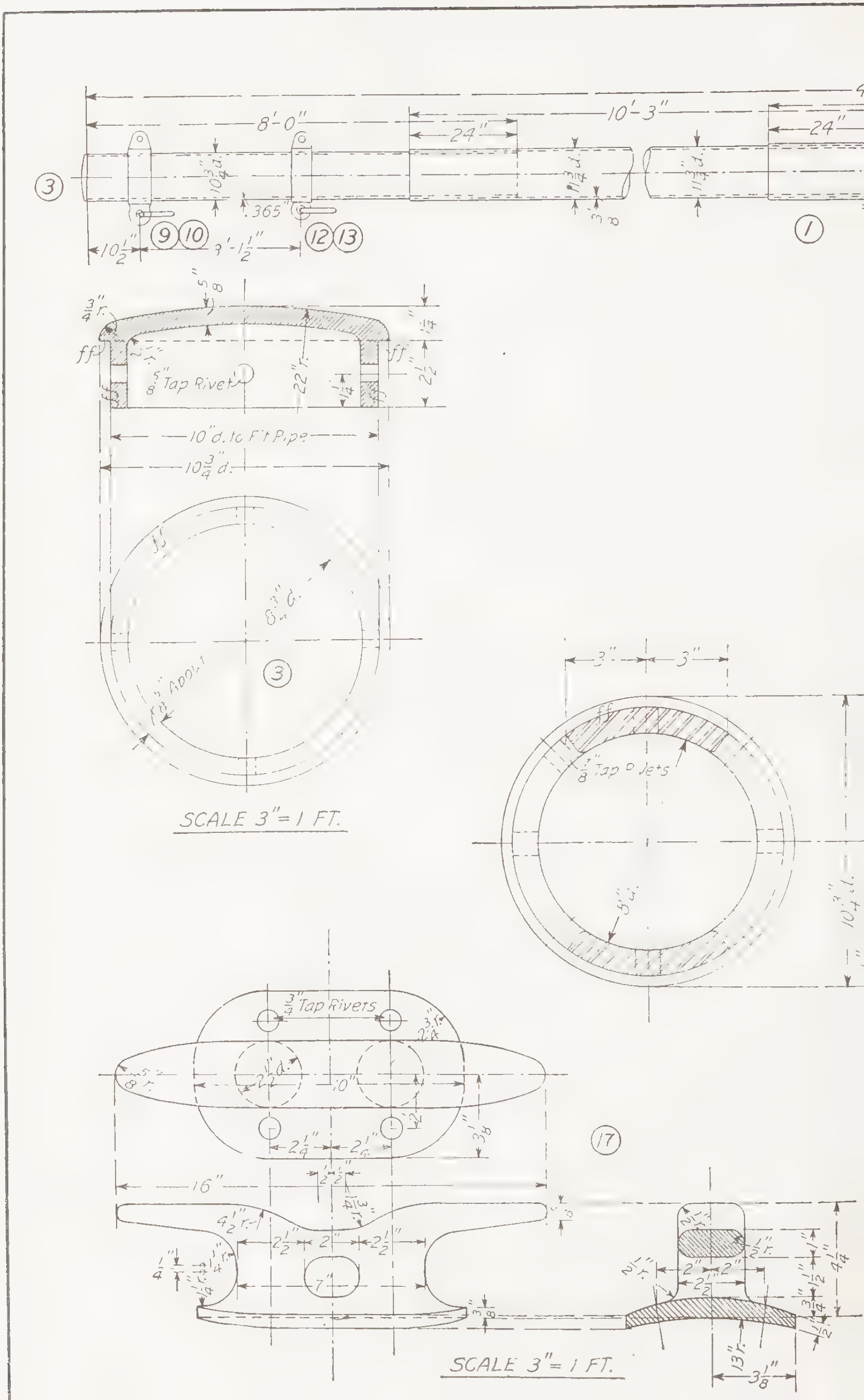
The washer, piece **18**, is to take the wear due to the tendency of the swivel pin to turn in the swivel as the boom is raised or lowered. This washer is shown only in this view and is drawn with the left side $1\frac{1}{16}$ inches from the end of the swivel pin. The washer is $\frac{1}{4}$ inch thick and $3\frac{1}{2}$ inches outside diameter. The inside diameter is $2\frac{9}{16}$ inches. The swivel pin is to be shown dotted in way of the washer.

The schedule of material, or the material list, for all the rigging details shown on Plates 1056 and 1057 is given on Plate 1057. This plate is to be finished by putting on all lettering, dimensions, etc., together with the title and number of the plate, in the usual manner.

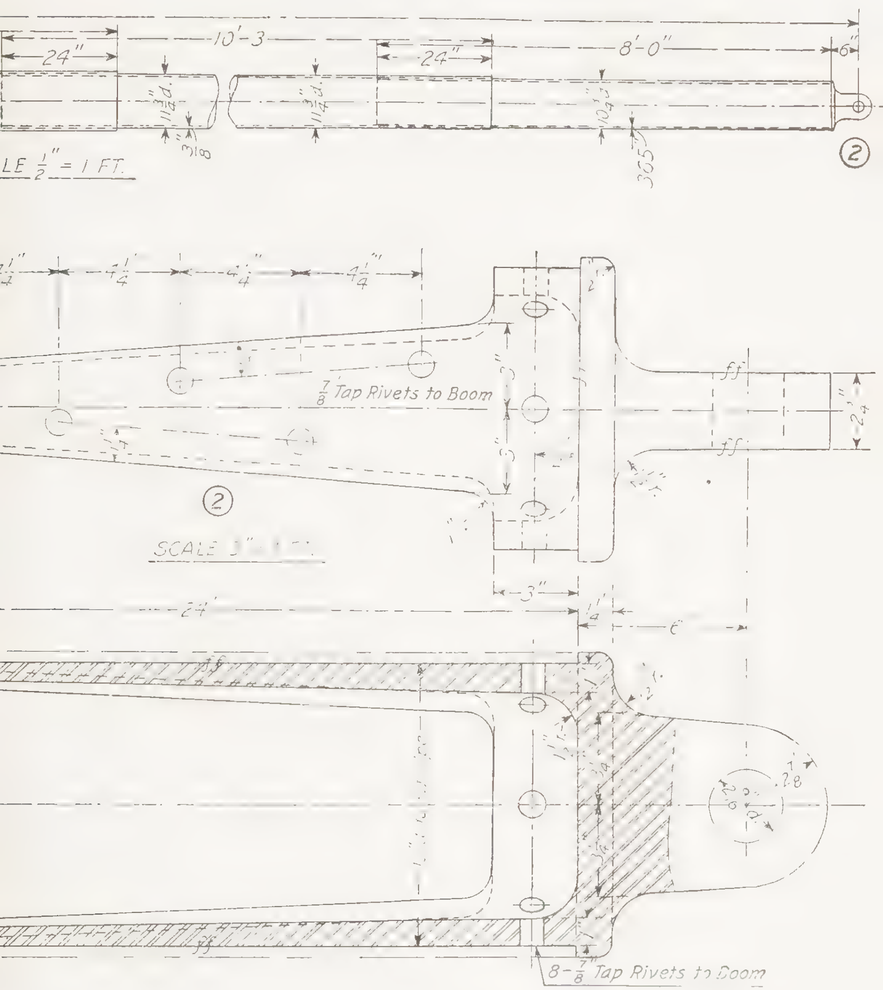
PLATE 1057: TITLE, CARGO BOOM AND FITTINGS

118. On Plate 1057 first draw the cast-iron boom cap, piece **3**. This is the piece that goes on the outer end of the boom, and is to be shown in plan and sectional elevation.

Locate the vertical axis $2\frac{1}{4}$ inches from the left-hand border and the horizontal axis for the plan view $5\frac{7}{8}$ inches below the top border. Draw the bottom of the sectional view of the cap $3\frac{5}{8}$ inches below the top border. Draw this cap 10 inches diameter, to scale, 5 inches each side the vertical axis. The cylindrical part which fits inside the tubular boom is $2\frac{1}{2}$ inches deep and $\frac{5}{8}$ inch thick. The 10-inch diameter is approximate because this part will be turned down to fit the exact inside of the boom. At the top of this cylinder is a shoulder that covers the end of the boom. This shoulder is $10\frac{3}{4}$ inches in diameter, having $\frac{3}{8}$-inch overhang on each side. The top of the cap is $1\frac{1}{4}$ inches above the under side of the shoulder and has a spherical form of 22-inch radius, the center being on the axis of the cap. This top tapers to the side of the shoulder by an arc of $\frac{3}{4}$-inch radius tangent to the arc of 22-inch radius. The top is $\frac{5}{8}$ inch thick, except near the sides,



8'-0"
10'-3"
24"
10 3/4" d.
11 3/4" d.
.365"
3/8"
10 1/2"
3'-1 1/2"
(3)
(9) (10)
(12) (13)
(1)
3/4" r.
5/8"
ff
5/8" Tap Rivet
22" r.
1 1/4"
1/4"
2 1/2"
10" d. to Fit Pipe
10 3/4" d.
8 3/4" d.
3"
7/8" Tap Bolts
8" d.
10 3/4" d.
3/4" Tap Rivets
2 1/2" d.
10"
3 1/8"
2 1/4"
16"
4 1/2" r.
2 1/2"
2"
7"
3/8"
13" r.
3 1/8"
4 1/4"
(17)
SCALE 3" = 1 FT.
SCALE 3" = 1 FT.



DETAILS ON PLATE 1056

Gooseneck Swivel	4	Medium Steel		
Shallow Nut	5	Medium Steel		
Swivel Pin	6	Medium Steel		
Locking Pin	7	Medium Steel		
1/8" Split Pins	8	Medium Steel		
Boom Band	9	Cast Steel	Pattern	D
Link	10	Medium Steel		
Links	11	Medium Steel		
Boom Band	12	Cast Steel	Pattern	E
Link	13	Medium Steel		
Shackle	14	Medium Steel		
Shackle Pin	15	Medium Steel		
Shackle Pin Nut	16	Medium Steel		
Washer	18	Medium Steel		

DETAILS ON PLATE 1057

1	Cargo Boom	1	Steel Tubing		
1	Gooseneck	2	Cast Steel	Pattern	A
1	Boom Cap	3	Cast Iron	Pattern	B
1	Cleat	17	Cast Iron	Pattern	C

CARGO BOOM & FITTINGS

DRAWN BY __________

DATE __________

1057

where it merges into the sides by an arc of $\frac{1}{2}$-inch radius tangent to both. Distant $1\frac{1}{4}$ inches above the bottom are four $\frac{5}{8}$-inch tap rivets, three of which are shown. The section should be cross-hatched to represent cast iron.

119. Next draw the plan, which in this case is a bottom view. With the intersection of the two axes as a center,

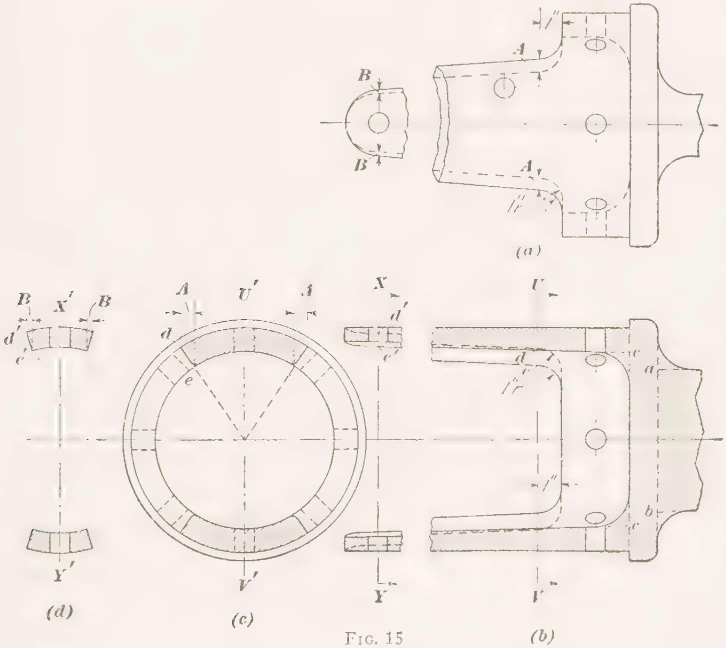


Fig. 15

draw circles having diameters of $8\frac{3}{4}$ inches, 10 inches, and $10\frac{3}{4}$ inches. The first represents the inside of the cylindrical part, the second the outside, and the last the edge of the shoulder, which comes flush with the outside of the tubular boom. Locate the four $\frac{5}{8}$-inch taps on the axes, showing them by parallel dotted lines $\frac{5}{8}$ inch apart. The outsides of the cylinder and the shoulder are file finished, which is to be indicated on the section by the letters $f\,f$.

120. Next draw the three views of the gooseneck, piece 2, which consists of a plan, sectional elevation, and a cross-section

to a scale of 3 inches=1 foot. Fig. 15 illustrates clearly how the various points in the different views are projected. Locate on the plate the horizontal center lines $4\frac{3}{16}$ and $7\frac{11}{16}$ inches, actual distance, respectively, from the top border. Also locate the two vertical center lines at distances of $1\frac{3}{8}$ and 11 inches, respectively, from the right-hand border.

At a distance of 6 inches, to scale, to the left of the center line through the hole in the lug, draw the shoulder, which sets up against the tubular boom.

This shoulder is $10\frac{3}{4}$ inches in diameter and $1\frac{1}{4}$ inches thick, and the outer edge is rounded with a $\frac{1}{2}$-inch radius, and being cylindrical it will have the same shape in the elevation. In the sectional elevation the lug for the swivel pin terminates in an arc of $2\frac{7}{8}$-inch radius, and the sides of the lug are drawn tangent to this arc and extending toward points $3\frac{1}{4}$ inches each side of the center line at the shoulder, as the points *a* and *b* in Fig. 15. The sides of the lug are connected to the shoulder by fillets of $1\frac{1}{2}$-inch radius.

In the plan view, draw the sides of the lug consisting of two lines parallel to and $1\frac{3}{8}$ inches each side of the horizontal center line and connected to the shoulder by fillets of $1\frac{1}{2}$-inch radius.

Draw the swivel-pin hole, to take piece **6**, making it of a diameter of $2\frac{9}{16}$ inches, which allows $\frac{1}{16}$-inch clearance for the swivel pin.

The elevation is to be shown mostly in section, except that part containing the lug. The part of the gooseneck to the left of the shoulder projects into the boom and is riveted to it.

Immediately to the left of the shoulder in the plan and elevation is a cylindrical portion 3 inches long and about 10 inches outside diameter. This latter dimension may be altered slightly in filing down the surface to fit the boom.

At the left end of this cylinder two prongs begin which extend 24 inches from the shoulder and are shown in the plan view to be symmetrical about the center line. The outer edges of the prongs in this view spread out toward the shoulder to 3 inches each side of the center line, and are connected to the shoulder by fillets of 1-inch radius.

In the elevation, the outside diameter of the prongs is 10 inches, showing them to be a continuation of the cylinder as seen in the plan view.

Each prong is $\frac{5}{8}$ inch thick at the extreme end, as shown in the elevation, and increases in thickness on the inside to 1 inch at the junction with the bottom of the shoulder as at points *c* and *c*, Fig. 15. The prongs and the cylinder to which they are connected are rounded into the shoulder on the inside by a fillet of $1\frac{1}{2}$-inch radius. The inside of the cylinder is shown dotted in the plan, as well as the inside edges of the prongs, the latter being obtained from the end view, as will be explained. In the elevation, the prongs and head up to $2\frac{1}{2}$ inches from the swivel-pin hole are cross-hatched for cast steel.

121. At the intersection of the two axes locate the end view on the plate, and draw three circles, 8 inches, 10 inches, and $10\frac{3}{4}$ inches in diameter. The first represents the inside diameter of the cylinder at its inner end, the second the outside diameter of the cylinder and the arc of the outer surface of the prongs throughout their length, and the last the shoulder against which the boom fits. In this view the section of the prongs where they join the cylindrical part is 6 inches wide and is to be shown cross-hatched. The flat sides of the prongs are shown by radial lines, and the inside edges of the prongs are rounded with a $\frac{1}{4}$-inch radius. The inner edges are to be shown projected to the plan and the elevation. In the elevation the inner far edges of the prong are full lines, and the outer far edges, being hidden behind the section, are dotted. In the plan view the inner, or under, edges of the top prong are represented by dotted lines. The location of these lines is obtained from the end section in the manner illustrated in Fig. 15, which shows views similar to those on the plate and also a section through *X Y*, near the end of the prong. View (*c*) is the same as the end elevation on the plate, and view (*d*) is a section through the outer rivet hole, which is $1\frac{1}{2}$ inches from the end of the prong. In views (*c*) and (*d*) similar points are lettered correspondingly; thus, *d′* corresponds to *d*, and *e′* to *e*, etc.

In ordinary practice, view (*d*) would be drawn in pencil and in outline only, to the left of view (*c*), and the lengths of the radii would be obtained by projection from the sectional elevation at the line *X Y*.

In these views *A* represents the horizontal distance between points *d* and *e*, and *B* the horizontal distance between points *d'* and *e'*. Then, to locate the inner edges of the prong on the plan view to be shown on the plate, these dimensions *A* and *B* may be transferred, by measurements, to their proper places as indicated on the plan in Fig. 15 (*a*), where *A* is 1 inch to the left of the cylindrical part and *B* 1½ inches from the end of the prong. The dotted lines may then be drawn through these points. On the plate, the inner surface of the end of the prong is represented by a dotted arc tangent to the end of the prong and to the two dotted lines that represent the inner edges. At the inner end, a dotted arc of 1-inch radius is drawn tangent to the dotted lines and to the inner end of the cylinder. In the side elevation, points locating the inner edges of the prong at the section lines *U V* and *X Y* may be projected directly from the sectional views (*c*) and (*d*). The similar points may be identified by similar letters.

At a distance of 1½ inches to the left of the shoulder, draw a center line on which to project rivet holes shown in the end view. Since the holes are on a cylindrical surface all holes not on the center line will be elliptical in form. The rivet holes in the prongs can be made circles, as it is a conventional method of representing them. In the elevation, only the end rivet hole in the prong is shown; the others in the prongs are omitted, since they would be of no real service in constructing the piece.

122. Next draw the cargo boom, piece **1**, with its horizontal center line 1½ inches below the top border. This is drawn to a scale of ½ inch=1 foot.

The boom is made up of five pieces of tubing, those of smaller diameter being set into the larger and welded in place. The end sections are 8 feet long by 10¾ inches outside diameter and .365 inch thick. The next sections are 10 feet 3 inches

long, $11\frac{3}{4}$ inches outside diameter, and $\frac{3}{8}$ inch thick. The middle piece is 18 feet long, $12\frac{3}{4}$ inches outside diameter, and $\frac{3}{8}$ inch thick. The smaller tubes are set 24 inches inside the larger ones so that the total length over the tubing is 40 feet 6 inches. The inside diameter of the $12\frac{3}{4}$-inch outside diameter tube is 12 inches, and the $11\frac{3}{4}$-inch outside diameter tube sets inside of this, leaving a quarter of an inch to be taken up. Locate the eye of the gooseneck, piece **2**, $\frac{3}{8}$ inch from the right-hand border and locate the end of the tube 6 inches from that eye as dimensioned in the detail of piece **2**. Locate the outer end of the $10\frac{3}{4}$-inch outside diameter tube at the opposite end of the boom $\frac{3}{4}$ inch from the left-hand border and draw the $10\frac{3}{4}$-inch outside diameter tubes to lengths given. Draw the three middle tubes, showing the laps 24 inches long. As the length of the paper is not sufficient for full length of the boom, show breaks in the three middle pieces. Make the lengths from the outer ends of the $11\frac{3}{4}$-inch tubes to the ends of the $12\frac{3}{4}$-inch tube $3\frac{5}{16}$ inches, actual measurement. Draw to reduced size the gooseneck, piece **2**; boom cap, piece **3**; outer and inner bands, pieces **9** and **12**, and show the links in the eyes of the bands, pieces **10** and **13**, parallel to the boom. The dimensions and lettering will complete this view.

123. Next locate the outer base line for the cleat, piece **17**, $\frac{7}{8}$ inch above the bottom border. This cleat is to be shown in plan, elevation, and sectional side elevation. The vertical center line, or axis, of the plan and elevation is 3 inches from the left-hand border, the center line of the section is $6\frac{1}{2}$ inches from the left-hand border, and the horizontal center line of the plan is $3\frac{1}{8}$ inches above the bottom border.

Draw the base in the plan view $6\frac{1}{4}$ inches wide and 10 inches long, the corners having a $2\frac{3}{4}$-inch radius. This base is symmetrical about the center line and axis. Locate the $\frac{3}{4}$-inch tap rivets as shown. Show the horn of the cleat 16 inches long—8 inches each side of the axis and terminating in an arc of $\frac{5}{8}$-inch radius. For a distance of 4 inches each side of the axis, the horn is $2\frac{1}{2}$ inches wide—$1\frac{1}{4}$ inches each side of the center line—and from the ends of this parallel part to the arc

at the end, it tapers in a fair curve tangent to both. The base is dotted in way of the horn.

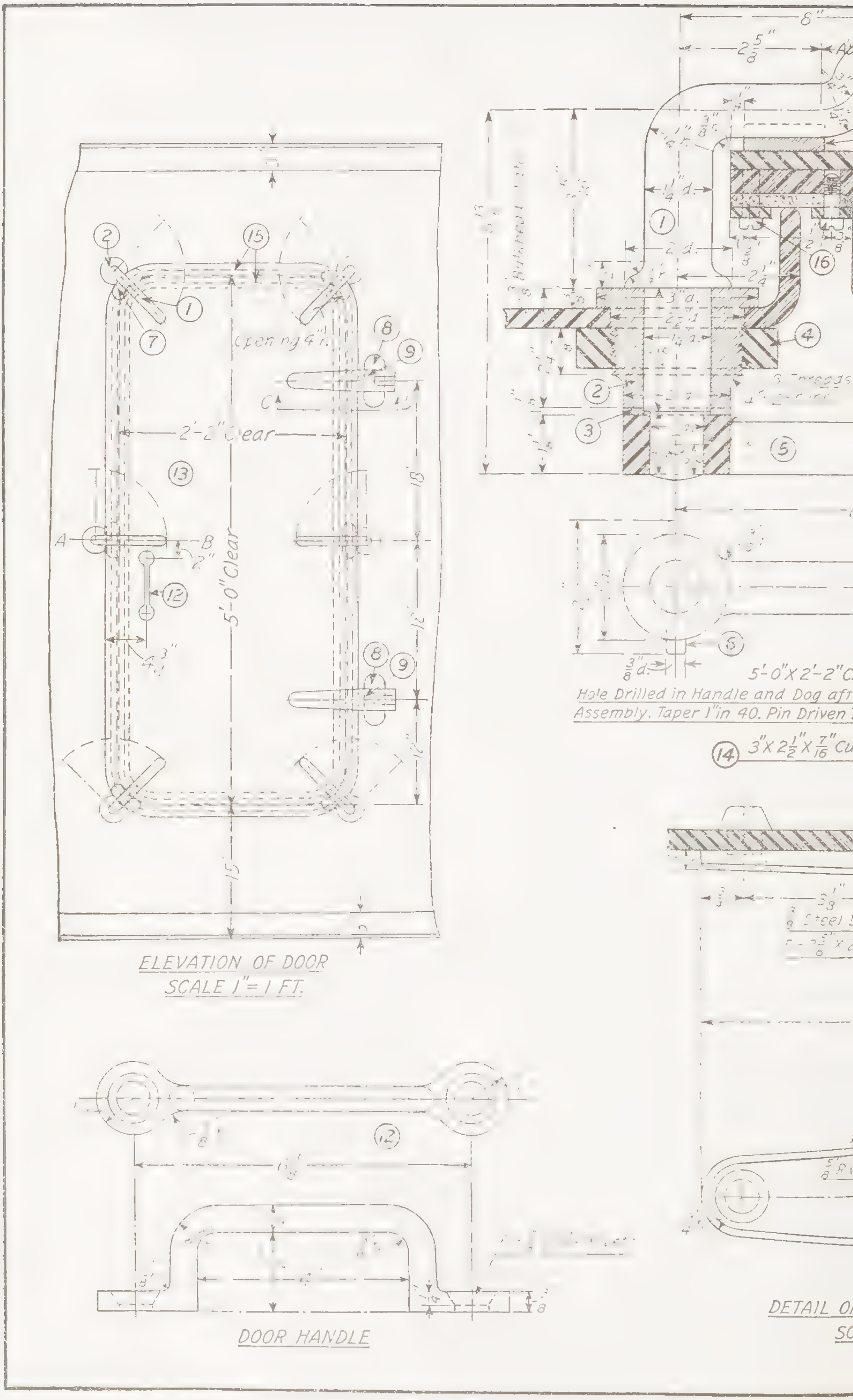
124. In the section, which is through the middle of the cleat, draw the bottom of the base tangent to the base line with a 13-inch radius whose center is on the center line continued below the figure. The base is concave so that the cleat can be riveted to a mast or other circular structure. This curved surface extends horizontally $3\frac{1}{8}$ inches each side of the center line. Make the edges of the base $\frac{1}{2}$ inch thick and vertical. The thickness of the base in the center is $\frac{3}{4}$ inch. Through the points that define the thickness at the center and side draw an arc of a circle.

125. In the elevation, locate the bottom of the ends of the base 5 inches each side of the center line and on the base line. The thickness of the base at the ends is $\frac{3}{8}$ inch. Project over from the section the top and bottom of the sides of the base. These sides are parallel with the base line only for a length of $2\frac{1}{4}$ inches each side of the center line, as the corners of the base are of $2\frac{3}{4}$-inch radius. On the base line lay off the length of the base and its thickness at the ends—$\frac{3}{8}$ inch—and connect the side lines with the thickness points at the ends by means of curves tangent to these lines. Locate the ends of the horn 8 inches each side of the center line, the top in the elevation being $4\frac{1}{4}$ inches above and parallel to the base line, except for a distance of 4 inches each side of the center line. The ends of the elevation of the horn are formed by arcs of circles $\frac{5}{8}$ inch in diameter. Locate the opening through the standard supporting the horn with its bottom at the top of the base; that is, $\frac{3}{4}$ inch above the base line as drawn in the cross-section. This opening is $1\frac{1}{2}$ inches deep, it extends 1 inch each side of the center line, and its ends are semicircles $1\frac{1}{2}$ inches in diameter. Draw vertical pencil lines $2\frac{1}{2}$ inches beyond the sides of this opening. With radii of $1\frac{1}{4}$ inches and centers $1\frac{1}{4}$ inches above the top of the base at the ends, draw arcs tangent to these lines. Then with radii of $1\frac{1}{4}$ inches and centers $\frac{1}{4}$ inch above the centers just used, draw arcs tangent to these pencil lines. Draw lines tangent to each pair of arcs,

and draw the under side of the horn as a straight line tangent to the upper arcs and to the $\frac{5}{8}$-inch-diameter arcs at the ends of the horns. The depth of the horn above the opening is 1 inch and the top of the horn is flat in elevation for a distance $\frac{1}{2}$ inch each side of the center. With centers $\frac{1}{2}$ inch from the middle of the length and radii of $1\frac{3}{4}$ inches, draw arcs tangent to this flat elevation; then, with radii of $4\frac{1}{2}$ inches draw arcs tangent to the preceding arcs and to the outer top contour of the horns. This completes the side elevation. The plan is completed by drawing dotted circles, $2\frac{1}{2}$ inches in diameter, with their centers on the center line and $2\frac{1}{4}$ inches each side of the axis. These represent the sections of the standard supporting the horn at each side of the opening.

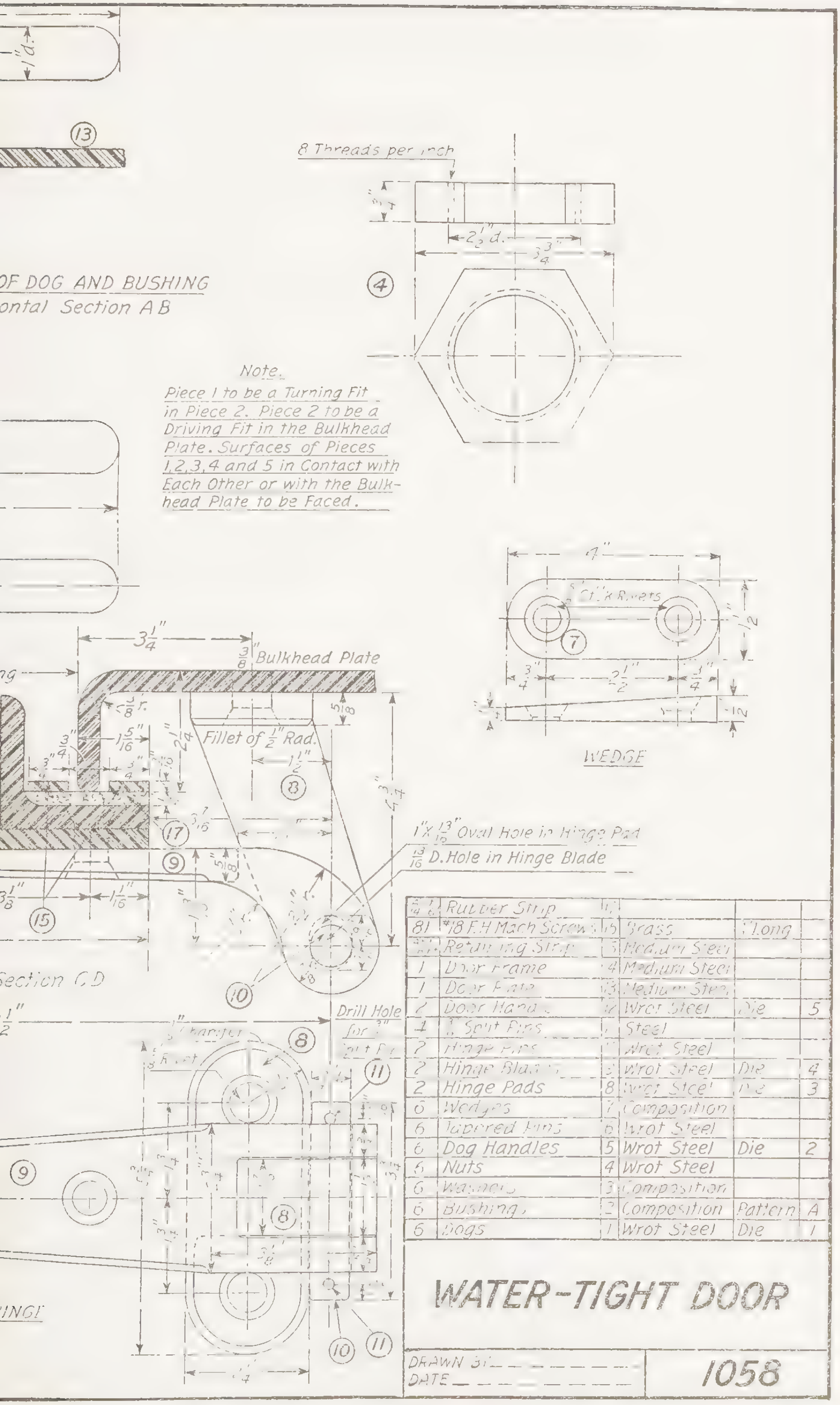
On the section draw vertical lines $1\frac{1}{4}$ inches each side of the center line and connect them to the top of the base by arcs of $\frac{1}{2}$-inch radii tangent to both. The projection of the top of the horn is flat and connects with the sides, which are the vertical lines just drawn, by arcs of $\frac{1}{2}$-inch radii tangent to both. Over the opening, the material is 1 inch in depth and $2\frac{1}{2}$ inches wide. The sides are semicircles of $\frac{1}{2}$-inch radius. This section is to be cross-hatched to represent cast iron.

Complete the plate by putting on all lettering, the list of parts, or details, as shown on both Plate 1056 and this one, and the title and number of this plate.



ELEVATION OF DOOR
SCALE 1"=1 FT.

DOOR HANDLE



[illegible]	Rubber Strip	17			
81	#18 F.H. Mach. Screws	16	Brass	[illegible] Long	
[illegible]	Retaining Strip	15	Medium Steel		
1	Door Frame	14	Medium Steel		
1	Door Plate	13	Medium Steel		
2	Door Handle	12	Wrot Steel	Die	5
4	[illegible] Split Pins	11	Steel		
2	Hinge Pins	10	Wrot Steel		
2	Hinge Blades	9	Wrot Steel	Die	4
2	Hinge Pads	8	Wrot Steel	Die	3
6	Wedges	7	Composition		
6	Tapered Pins	6	Wrot Steel		
6	Dog Handles	5	Wrot Steel	Die	2
6	Nuts	4	Wrot Steel		
6	Washers	3	Composition		
6	Bushings	2	Composition	Pattern	A
6	Dogs	1	Wrot Steel	Die	1

WATER-TIGHT DOOR

DRAWN BY
DATE

1058

SHIP DRAFTING
(PART 3)

DRAWING PLATES—Continued

PLATE 1058, TITLE: WATER-TIGHT DOOR

1. Frequently it is desirable and sometimes it is necessary to have access to various compartments of a vessel through water-tight bulkheads. In such cases water-tight doors are required. Obviously it would be ridiculous to have a water-tight bulkhead with a non-water-tight door in it. Water-tight doors are of two kinds, hinged and sliding. The door shown in Plate 1058 is of the hinged variety. Sliding doors are either hand-operated or power-operated. The power-operated doors can be opened and closed from a distance—as from the bridge. Doors that are operated from the bridge are usually below or at the water-line, and in case of danger it is desirable to close them much quicker than could be done by hand at the door. Hence, on passenger steamers, doors operated by electric or hydraulic power and worked from the bridge are desirable. These doors are more complicated than the hinged type. Hinged doors are used almost entirely on freight steamers, and on passenger steamers at places well above the water-line, where immediate closing is not so essential. In freight steamers, practically all water-tight doors near or below the water-line are kept closed when the vessel is at sea.

2. The door to be drawn in Plate 1058 is an ordinary type of hinged door and can be economically built. When closed,

it is made tight by means of six hand-operated dogs that, by a wedging action when turned, jam the door firmly against a flange on the bulkhead plate all around the sides of the door opening, the joint being made tight by a rubber strip between the door and the flange.

The views to be shown on this plate are an elevation of the door; a detail of the dog, and a section of its bushing and the door; a sectional view through the door with a plan and elevation of the hinge; and details of some of the smaller parts. The door plate, piece **13,** is stiffened around its edge by the door frame, piece **14,** which is an angle planed down from a larger size to have a square toe that is flush with the edge of the door plate. Secured to the riveted flange of this angle by the two retaining strips, pieces **15,** is a strip of rubber, piece **17,** $\frac{1}{4}$ inch thick. The door swings on two hinges made up of the hinge pad, piece **8,** the hinge blade, piece **9,** riveted to the door plate, and the hinge pin, piece **10,** connecting pieces **8** and **9.**

An oval hole in piece **8** permits the pin, and hence the door, to be moved toward the bulkhead when the dogs are jammed down on the wedges. Piece **10** is held in place by two $\frac{3}{16}$-inch split pins, pieces **11.** The door opening is 2 feet 2 inches$\times$5 feet in the clear and the bulkhead plate is flanged $2\frac{1}{4}$ inches around the sides of the opening. When the door is closed the rubber between the retaining strips, pieces **15,** is in contact with the flange of the bulkhead plate. Water-tightness is obtained by forcing the rubber against the flange by means of the six dogs, pieces **1,** that pass through the bulkhead and are turned by handles, pieces **5,** from the opposite side of the bulkhead. The dog when turned forces the rubber against the flange by sliding over the wedge, piece **7,** which is riveted to the door in way of the travel of the dog. The offset in the dog is made so that there is clearance between it and the door plate for a man's hand, thus making a handle so that the dog can be operated from either side of the bulkhead. The shank of the dog is turned to $1\frac{1}{4}$ inches in diameter and this part is a turning fit in the bushing, piece **2,** which is tightly fitted in the $2\frac{1}{2}$-inch-diameter hole in the bulkhead plate. This bushing is held in

place by the nut, piece **4**. To take the wear, there is a washer, piece **3**, inserted between the handle and the bushing. All contacting surfaces of pieces **1**, **2**, **3**, **4**, and **5** are machined. While there might be a slight seepage of water through this assembly, there can be no great leakage. A door handle, piece **12**, is riveted on each side of the door.

3. First draw the Detail of Dog and Bushing, to a scale of 6 inches = 1 foot. This view represents a horizontal section taken on *A B* in the Elevation of Door, which is the assembly drawing. Draw the $\frac{3}{8}$-inch bulkhead plate with its bottom side 3 inches, actual distance, from the top border, and the right-hand side of the $2\frac{1}{4}$-inch flange on the bulkhead plate $7\frac{7}{16}$ inches, actual distance, from the left-hand border. The dimensions for the flange are shown in the horizontal section on *C D* in the Detail of Door and Hinge. The toe of the flange is a semicircle described with $\frac{3}{16}$-inch radius and is drawn to scale. Locate the center line of the dog $2\frac{1}{4}$ inches from the face of the flange. Draw the bushing, piece **2**, washer, piece **3**, and shank of the dog, to dimensions. The end of the shank is hemispherical and of a radius equal to one-half the diameter, which at this part is 1 inch.

4. The handle, piece **5**, can also be drawn as shown. The axis for the lower, or plan, view of the handle is $5\frac{7}{16}$ inches, actual distance, below the top border. The end of the handle is of $\frac{1}{2}$-inch radius. The pin, piece **6**, is $\frac{3}{8}$ inch in diameter at its large end, and, according to the note on the plate, it is to taper 1 inch in 40 inches. Therefore, as it is $2\frac{1}{2}$ inches, or $\frac{40}{16}$ inches, long it will taper $\frac{1}{16}$ inch and its diameter at the small end will be $\frac{5}{16}$ inch. The hole in the shank of piece **1** is not dimensioned, on account of its being in the taper, but should be drawn a little less than $\frac{3}{8}$ inch in diameter.

5. At a distance of $3\frac{5}{16}$ inches above the top of the bushing, piece **2**, is the bend in the dog, the diameter below the bend being $1\frac{1}{4}$ inches and beyond it 1 inch. The parallel sides of these parts should be drawn in pencil intersecting and then connected by an arc of $\frac{3}{8}$-inch radius for the inside and of $1\frac{1}{4}$-inch radius for the outside of the bend. The profile of the

shoulder of the shank immediately above the bushing is a reverse curve, the center of the $\frac{1}{4}$-inch radius of the upper curve being $\frac{1}{2}$ inch above the bushing and the arc being tangent to the outline of the shank. The lower arc of $\frac{1}{4}$-inch radius is tangent to the upper arc and defines the edge of the shoulder, which is 2 inches in diameter. At a distance of $2\frac{5}{8}$ inches from the vertical axis is a offset of 1 inch which is made through a length of about $1\frac{7}{16}$ inches, beyond which point the dog continues parallel to the part immediately around the right-angle bend. With a center $2\frac{5}{8}$ inches to the right of the vertical axis and a radius of $\frac{3}{4}$ inch, draw an arc tangent to the horizontal axis. With the same radius, draw an arc tangent to the first arc and also to the offset axis. The second center will be about $1\frac{7}{16}$ inches to the right of the first center. The radii of the inside and the outside of the dog at each bend will have the same centers, and the arm being 1 inch in diameter the radii will be $\frac{1}{2}$ inch less and $\frac{1}{2}$ inch greater, respectively, than the radius of the axis.

6. As shown in the horizontal section in Detail of Door and Hinge, the door projects $1\frac{5}{16}$ inches beyond the inner face of the flanged bulkhead plate. Draw the $\frac{3}{8}$-inch thick door plate, piece **13**, with its upper edge located $1\frac{5}{16}$ inches, actual distance, from the upper border line, which will bring the top face of the plate $\frac{1}{4}$ inch from the lower side of the dog. Next draw the section of the wedge, piece **7**, $\frac{1}{4}$ inch from the edge of the doorplate. The detail of the wedge shows it to taper from $\frac{1}{2}$ to $\frac{1}{4}$ inch in thickness and its width to be $1\frac{1}{2}$ inches. Show dotted the high part of the wedge, $\frac{1}{2}$ inch thick, back of the dog handle. Though, as shown in the detail drawing, the ends of the wedge are rounded, it is here represented conventionally and the thin edge is cross-sectioned. Draw the angle, piece **14**—dimensions to be obtained from the hinge detail—having a $\frac{1}{4}$-inch radius at the toe and a $\frac{5}{16}$-inch radius at the bosom. The strip of rubber and the steel holding strips are drawn as dimensioned in the hinge detail. If the work has been drawn carefully, the toe of the flange and the surface of the rubber will be just touching. When the door is wedged

tight, the flange sets down into the rubber. The dimensions of the No. 18 fillister-head screws, $\frac{3}{4}$ inch long under the head, are to be taken from the table given in *Mechanical Drawing*. The holes for these screws extend through the angle. The screws are staggered in the two strips, and in each row they are spaced 4 inches center to center.

7. The detail of the wedge, piece **7**, is next drawn with the center line of the plan $5\frac{1}{16}$ inches, and the base of the elevation $6\frac{1}{16}$ inches, below the top border. The center of the right-hand rivet is $1\frac{7}{16}$ inches from the right-hand border. The drawing of this detail needs no explanation except that the countersink for the rivets is $\frac{1}{4}$ inch below the surface of the wedge.

8. The detail of the nut, piece **4**, is drawn with the vertical axis 3 inches from the right-hand border and the horizontal axis of the plan $3\frac{1}{4}$ inches below the top border. The bottom of the elevation is 2 inches below the top border. The plan is drawn first as a hexagon inside a circle of $3\frac{3}{4}$ inches diameter, to scale. The dotted circle $2\frac{1}{2}$ inches in diameter represents the root of the thread; and the full circle, which is drawn about $2\frac{1}{2}$ inches in diameter, represents the top of the thread.

9. The Detail of Door and Hinge shows a horizontal section at *C D* of the assembly drawing, and is drawn by first locating the bulkhead plate with the top side $6\frac{3}{16}$ inches above the bottom border and the outside (left) of the flange $7\frac{1}{16}$ inches from the right-hand border. Draw the door plate, the angle, piece **14**, and the rubber and retaining strips in the same way as in the detail of the dog, the door plate being shown broken away. The center of the hinge pad, piece **8**, is $3\frac{1}{4}$ inches from the flange of the bulkhead plate and the pad is $\frac{5}{8}$ inch thick.

Draw the center line of the elevation of the hinge $1\frac{7}{8}$ inches above the bottom border and project down the center of the hinge pad from the plan view. Draw the base of the pad as per dimensions. The chamfer extends back $\frac{1}{8}$ inch from the corner of the top of the base. In the plan, locate the center

of the hinge pin, piece **10,** and also the center of the hinge-pin hole in the hinge blade, piece **9,** $4\frac{3}{4}$ inches from the bulkhead plate or base of the pad and $1\frac{1}{2}$ inches to the right of the center of the pad. With this center and a radius of $\frac{7}{8}$ inch, draw an arc, from which draw tangents to the outer edges of the base, thus representing the projecting lug of the hinge pad on which the upper fork of the hinge blade rests when in place. Project this on the elevation, making it $1\frac{7}{16}$ inches thick and symmetrical about the center line. A note on the plan view indicates a fillet of $\frac{1}{2}$-inch radius where the lug joins the base. Draw the blade of the hinge in the plan from the given dimensions. The pin end of the blade in the plan is of $\frac{7}{8}$-inch radius, same as the lug on the pad, and is connected to the blade by arcs of $2\frac{1}{2}$ inches and $1\frac{1}{2}$ inches radii tangent to the $\frac{7}{8}$-inch-radius arc and to the straight back and front of the blade. The hinge-pin hole in the blade is $\frac{13}{16}$ inch in diameter and is drawn as a full circle in the blade; in the pad, piece **8,** the hinge-pin hole is $1'' \times \frac{13}{16}''$ oval located as shown, and drawn dotted. Draw the elevation of the blade, dotting in the projection of the holes in the forked end and the countersunk holes in the pad. Locate the centers for three $\frac{5}{8}$-inch rivets in the plan of the blade, showing the countersunk heads dotted 1 inch in diameter, and project the centers to the elevation.

Draw the hinge pin, piece **10,** and locate the holes for the split pins where shown. The upper hole will be tangent to the top of the hinge blade.

10. The Door Handle, piece **12,** is next drawn by locating the axis of the plan $2\frac{3}{4}$ inches above the bottom border, and the base line of the elevation $\frac{3}{4}$ inch above the border. Locate the center of the left-hand rivet hole $1\frac{1}{4}$ inches from the left-hand border; and at a distance of $6\frac{3}{8}$ inches, to scale, to the right draw a center line for the right-hand rivet hole. In the plan view draw two arcs of $\frac{11}{16}$-inch radius for the pads and connect them to the sides of the $\frac{1}{2}$-inch-wire-diameter handle by arcs of $\frac{5}{8}$-inch radius tangent to the sides of the pads and the handle. The elevation may now be drawn from dimensions given and the outside curve in the handle may be projected to

the plan view. Draw dotted lines for $\frac{5}{8}$-inch countersunk rivet holes and show the bevel of the countersink at an angle of 60° and $\frac{1}{4}$ inch deep. The circles for the countersunk rivets in the plan may then be drawn.

11. Finally, draw the assembly view, or Elevation of Door, with the bottom of the bulkhead $4\frac{1}{4}$ inches above the bottom

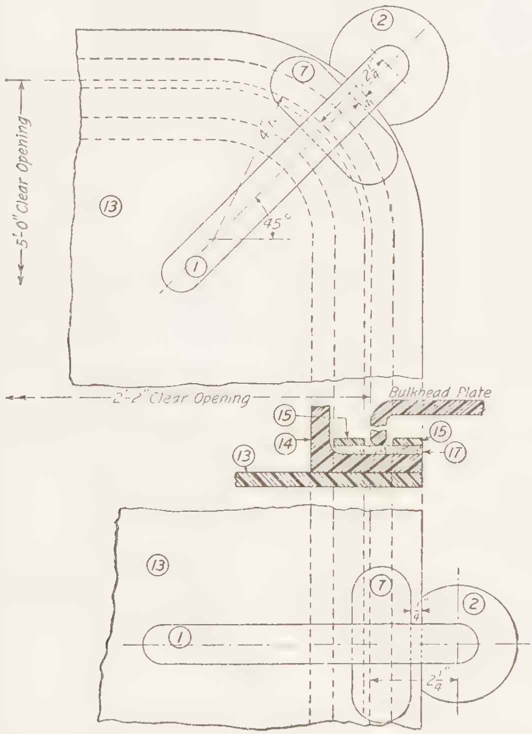


Fig. 1

border. Locate the left side of the clear opening in the door $1\frac{1}{16}$ inches from the left-hand border and show it dotted as in Fig. 1. The scale of this drawing is 1 inch = 1 foot. The bottom of the door is 15 inches, to scale, above the bottom of the bulkhead.

The height of the bulkhead is 7 feet 6 inches, and at the top and bottom is shown the 3-inch vertical leg of the bounding

angle bars. The bulkhead is shown broken at the sides. First draw the sides, top, and bottom of the door opening, rounding the corners with a 4-inch radius. The five dotted lines and one full line in this detail are shown more clearly in Fig. 1.

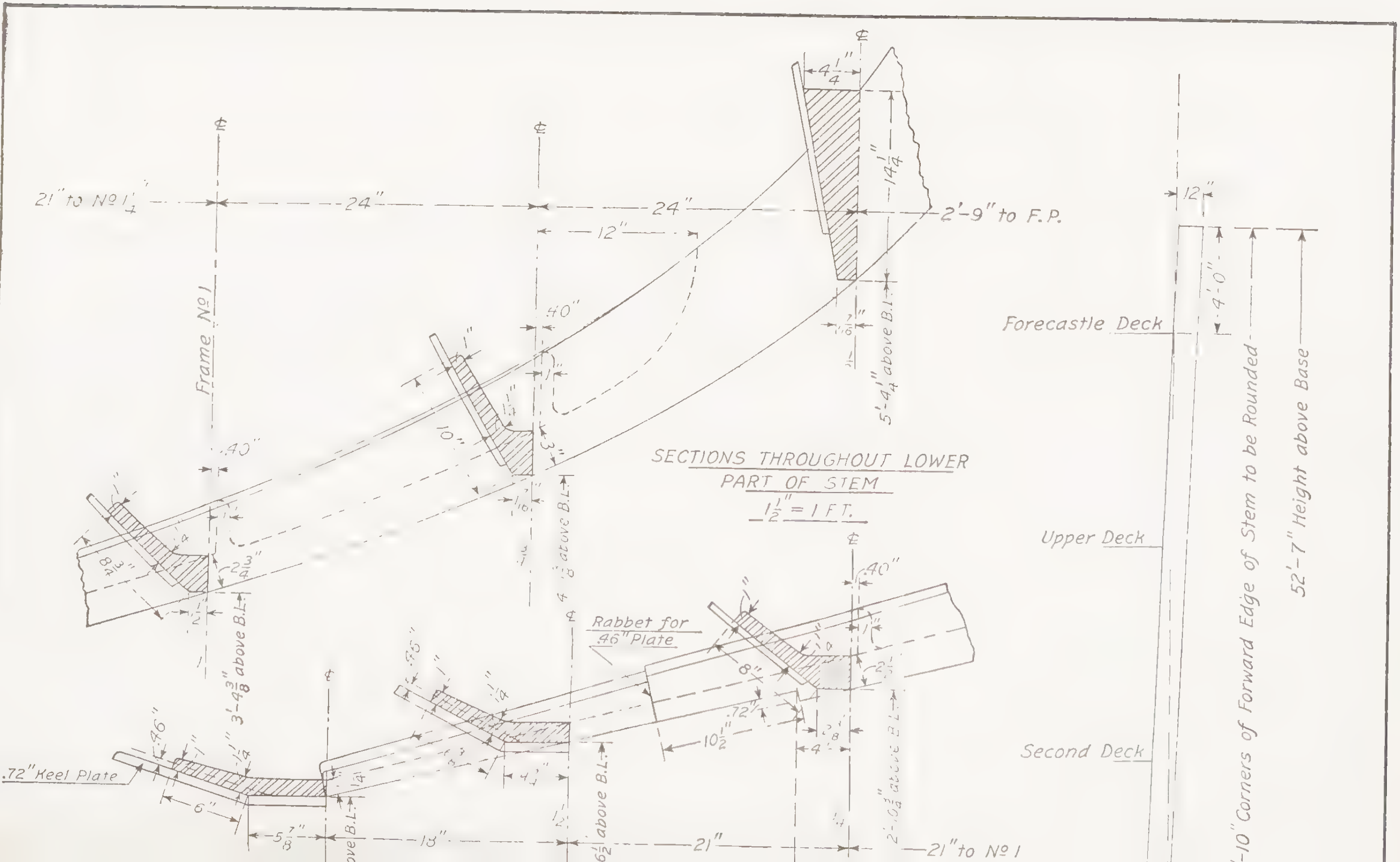
The lines of the door opening being taken as a base, the others are all parallel, and the center for all the radii at each corner is the same. Locate the center lines of the hinges from the given dimensions and draw the outline of the blade, piece **9**, and pad, piece **8**, referring to the detail drawing for dimensions. The center line of the hinge pad, piece **8**, is located $3\frac{1}{4}$ inches from the line of the door opening, and the center line of the hinge-pin holes is $3\frac{7}{16}$ inches from the edge of the door plate, piece **13**, which is represented by the outside full line in this assembly drawing. Next to be located are the center lines of the six dogs, those for the corners being along lines bisecting the corner angles. The center of the bushing, piece **2**, which is represented by the 3-inch-diameter circle, is located $2\frac{1}{4}$ inches from the door opening or door side line. The handle of the dog, piece **1**, is drawn along the center line and extending 8 inches inside the center line of the dog and bushing. Draw the outline of the wedge symmetrical about the center line of the dog and with its straight edge $\frac{1}{4}$ inch from the edge of the door. Finally locate and draw the door handle where shown.

Complete the plate by adding the dimensions, lettering, bill of materials, and title and number of plate in the usual manner.

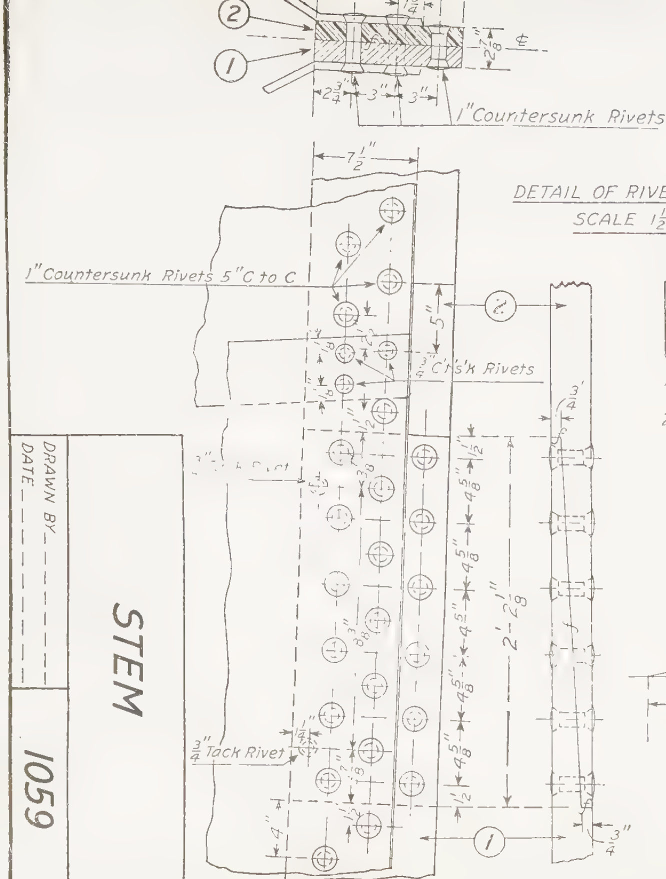
PLATE 1059, TITLE: STEM

12. The **stem** is the extreme forward member of the structure of a vessel and serves to unite the two sides of the ship. It is sometimes drawn in connection with the structural framing at the bow of the vessel and sometimes drawn separately. The latter method is preferable although the outline is required in the bow-framing drawing.

In the case here illustrated the stem consists of two parts: Piece **1**, a steel casting, known as the forefoot casting, which



SECTIONS THROUGHOUT LOWER PART OF STEM
1½" = 1 FT.
Forecastle Deck
Upper Deck
Second Deck
52'-7" Height above Base
Corners of Forward Edge of Stem to be Rounded
2'-9" to F.P.
21" to No 1¼
21" to No 1
Frame No 1
Rabbet for .46" Plate
.72" Keel Plate
5'-4¼" above B.L.
3'-4⅜" above B.L.



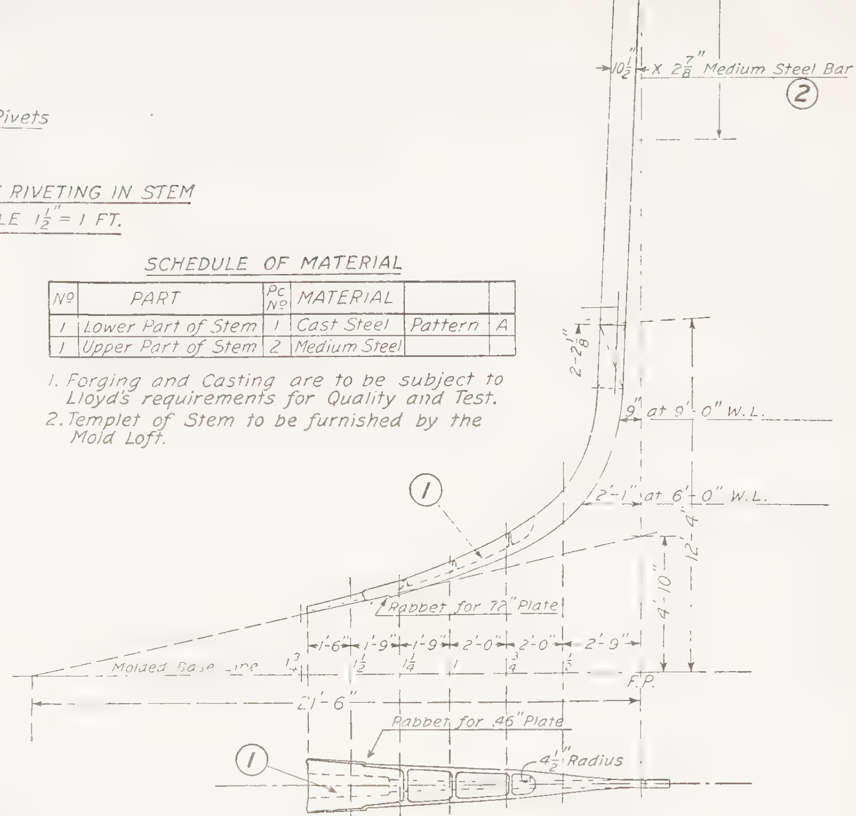
DETAIL OF RIVETING IN STEM

SCALE $1\frac{1}{2}" = 1$ FT.

SCHEDULE OF MATERIAL

Nº	PART	Pc Nº	MATERIAL		
1	Lower Part of Stem	1	Cast Steel	Pattern	A
1	Upper Part of Stem	2	Medium Steel		

1. Forging and Casting are to be subject to Lloyd's requirements for Quality and Test.
2. Templet of Stem to be furnished by the Mold Loft.



PLAN AND ELEVATION OF STEM

SCALE $\frac{1}{4}" = 1$ FT.

STEM

DRAWN BY ________

DATE ________

1059

extends throughout that part of the stem where there is a varying cross-section, or where the shape is continually changing, and piece **2**, a mild-steel bar of constant cross-section extending from the forefoot casting to the top. By reference to the Lines drawing, Plate 1051, it will be seen that the ship's form narrows down, or "fines in," from station $\frac{1}{2}$ forward. It is to conform to this change in shape at the bottom that the casting is used. In this case the half siding decreases from $5\frac{7}{8}$ inches at the after end of the casting to $1\frac{7}{16}$ inches at the forward end, and this latter dimension is one-half the thickness, or is the *half siding,* of the stem bar. At the lower end of the stem, as elsewhere, the frames of the vessel must *fair in* to this half-siding line. This lower part of the stem is sometimes made a continuation of piece **2** and then this fairness and changing of shape is attained by forging in the shop to templets made in the mold loft. The method here illustrated requires a pattern, which is made to dimensions taken from the mold-loft floor. It will be seen that at each section the half siding is given but not the width at the top of the flange, or the upper edge. The patternmaker must get these dimensions directly from the full-sized Lines on the mold-loft floor.

13. The stem here illustrated is for a longitudinal-framed vessel where the transverses, or frames, are not regularly spaced at the extreme end of the vessel. The Lines of this vessel would show that a forefoot casting having cross-sections as here shown would be fair and would also fair in with the framing and the shell above, that is, it would join on without any hollows or humps.

Above the forefoot, the two sides of a vessel have much less curvature and what there is changes more gradually. The shell plating is here knuckled at or near the after edge of the upper stem, piece **2**, and is through riveted. The two parts of the stem are connected by a scarf joint, the surfaces of which are machined to fit.

The drawing of the stem consists of a plan and elevation showing the general arrangement, and several details. Aside from the riveting and the scarf joint, the upper part can be

made from the elevation of piece **2**, but the details are necessary for making the lower part, piece **1**. The plan and elevation show views drawn to scale, but not specially working drawings. The cross-sections give the transverse shape at certain definite points, and by making templets of each of these sections, from the mold-loft floor, the patternmaker can shape his full-size pattern so it will come in a fair surface throughout. A templet is made of the upper part of the stem for marking holes for riveting to the shell plating and to piece **1**.

14. Draw the molded base line $1\frac{7}{8}$ inches, actual measurement, above the lower border line. Then, 2 inches from the right-hand border, draw the forward perpendicular (*F. P.*). Dimensions on the figure, from here on, are to be laid off to a scale of $\frac{1}{4}$ inch = 1 foot. From a point on the base line 21 feet 6 inches aft of the forward perpendicular, draw a dash line to intersect the forward perpendicular in a point 4 feet 10 inches above the base line. Mark a point on the forward perpendicular 25 feet 6 inches above the base line. Locate the top of the stem 52 feet 7 inches above the base line and locate the forward edge 12 inches forward of the forward perpendicular at this height. From this point draw the forward edge of the stem straight from the top through the 25-foot-6-inch point previously located and extend it to 10 feet above the base line.

Draw in pencil lightly the 6-foot and 9-foot water-lines. Draw the dash lines representing frames $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$, and $1\frac{3}{4}$, the first five located as shown on the drawing and the last 1 foot 9 inches aft of frame $1\frac{1}{2}$. At frames $\frac{1}{2}$, $\frac{3}{4}$, 1, and $1\frac{1}{4}$, respectively, mark points 5 feet $4\frac{1}{4}$ inches, 4 feet $1\frac{3}{8}$ inches, 3 feet $4\frac{3}{8}$ inches, and 2 feet $10\frac{3}{4}$ inches above the base line. These dimensions may be seen on the sectional views of the stem. Locate points 9 inches and 2 feet 1 inch aft of the forward perpendicular on the 9-foot and the 6-foot water-lines, respectively. Through these points, with a ship curve, draw a line fairing into the line representing the forward edge of the stem just drawn. This will be the contour of the stem. This line extends aft of frame $1\frac{1}{4}$ a distance of about 4 inches (see large section at frame $1\frac{1}{4}$), being parallel to the dead-rise line

at this point and .72 inch below it. Of course, the .72 inch cannot be scaled. The stem contour aft of the rabbet continues along the dead-rise line to a point 1 foot 6 inches—measured horizontally—aft of frame $1\frac{1}{2}$. Show the shoulder 4 inches aft of frame $1\frac{1}{4}$. Beginning at the top, draw the back edge of the stem $10\frac{1}{2}$ inches from the front edge down to a point 10 feet above the base line. Indicate by short full lines the forecastle deck, upper deck, and second deck, 4 feet, 12 feet, and 20 feet, respectively, below the top of the stem. At a point 12 feet 4 inches above the base line show by a full line the top of the scarf joint between pieces **1** and **2**, then, 2 feet $2\frac{1}{8}$ inches below this line, draw the dotted line and designate the scarf by the two diagonal lines. The forward edge of the stem is rounded for a distance of 33 feet 10 inches downwards from the top; this, however, is indicated in this view by the lettering only.

15. Next draw the Detail of Riveting in Stem to a scale of $1\frac{1}{2}$ inches = 1 foot. Locate a point $3\frac{7}{8}$ inches from the left-hand border line and 4 inches above the lower border, actual measurement; this point is the top of the scarf on the front edge of the stem. Through this point and extending $2\frac{3}{8}$ inches above and $3\frac{7}{8}$ inches (actual measurement) below it, draw a line that is parallel to the fore side of the stem shown in the elevation already drawn. Draw the after side of the stem as a dotted line $10\frac{1}{2}$ inches, to scale, aft of the front, the bar portion of the stem being $10\frac{1}{2}$ inches by $2\frac{7}{8}$ inches, as shown in the section. Parallel to the after edge and $7\frac{1}{2}$ inches from it, draw a full line nearly as long as the front edge. Aft of this line just enough to show a space between, draw another full line of the same length. These full lines represent the forward chamfered edge of the shell plating lapping on the stem bar. Show the stem broken off at the top and bottom ends.

Draw, in full lines and dash lines as shown, the top and bottom of the stem scarf, perpendicular to the edges of the stem, the scarf being 2 feet $2\frac{1}{8}$ inches long. Locate on the forward edge of the shell plate points from which to draw the landing edge and the side edge of the shell seam, $2\frac{1}{2}$ inches and 7 inches,

respectively, above the top of the scarf. Show the seam, with a lap of $4\frac{1}{2}$ inches, extending aft from these points and sloping downwards 1 inch in 21 inches. Show part of the upper, or in, plate with its after and upper edges broken away, and show the lower, or out, plate with the lower and after edges broken away.

16. Next to be drawn is the cross-section view through the middle of the scarf. Draw a dot-and-dash line $3\frac{7}{16}$ inches, actual measurement, above the top of the scarf and perpendicular to the front of the stem. This is the center line of the section taken through the middle of the scarf. Draw the rectangle $10\frac{1}{2}$ inches by $2\frac{7}{8}$ inches, to scale, with a full line through the center indicating the joint between the steel-bar stem above and the cast-steel forefoot below. Locate the center lines of the rivets as shown and also the forward edge of the shell plate. Draw the plates in section, $\frac{1}{2}$ inch thick, the part aft of the stem sloping at an angle of 30 degrees to the center line or to agree with the shape of the ship. Draw the inner and outer rivets full and the middle rivet dotted. The rivets are 1 inch in diameter and the countersink may be shown as 30 degrees to the center line of the rivet. When the rivets pass through the plate, the countersink is only in the plate, but in the forward rivets the countersink is $\frac{1}{2}$ inch below the face of the stem bar and of the forefoot casting. Draw the convex, or *full,* heads and points of the rivets with a radius of $3\frac{1}{2}$ inches. Show the cross-hatching for wrought steel above and cast steel below.

From the section, project the rivet lines onto the elevation and show them as dash lines, the forward row extending only throughout the scarf. In the middle row, locate the top and bottom rivets of the scarf $3\frac{7}{8}$ inches from the ends of the scarf and show the three rivets equally spaced between. In way of the scarf, the top and bottom rivets of the inner and outer rows are located $1\frac{1}{2}$ inches from the ends of the scarf and four intermediate rivets are spaced $4\frac{5}{8}$ inches apart. The notes under the riveting tables, Tables I, II, and III, in *Ship Drafting,* Part 1, state that stem and stem-frame rivets are to be spaced

5 diameters. By locating the two rivets below the scarf as shown, this spacing is held.

The $\frac{3}{4}$-inch rivets through the plate seam are $1\frac{1}{8}$ inches, equal to $1\frac{1}{2}$ diameters, from the edges of the seam. The rivet in the outer row of plate rivets between the seam and the scarf is located the same as the corresponding rivet below the scarf. Above the plate seam, the rivets are so located that the spacing is exactly 5 diameters. The only places where the rule spacing is exceeded is at the ends of the scarf where at the bottom of the scarf the inner rivets are $4+1\frac{1}{2}=5\frac{1}{2}$ inches apart, and those in the outer row at both top and bottom are $3\frac{7}{8}+1\frac{1}{2}=5\frac{3}{8}$ inches apart.

Locate the $\frac{3}{4}$-inch tack rivets in the scarf as shown. The 1-inch rivets are shown by a full circle $1\frac{3}{4}$ inches in diameter and a dotted circle 1 inch in diameter; the $\frac{3}{4}$-inch rivets are shown by a $1\frac{1}{4}$-inch full and a $\frac{3}{4}$-inch dotted circle.

17. Next, the front view of the stem is to be drawn. First, draw a solid line $4\frac{3}{4}$ inches (actual measurement) from the left border and perpendicular to the lower border. This line is the left-hand side of the front view of the stem. Project over the top and bottom of the scarf and draw the end view, showing the scarf tapering to $\frac{3}{4}$ inch at the ends. Show the rivets in the outer row dotted in this view.

Note that the rivet spacing is given along the stem in the side view, instead of on the end view which is a projection and not a view looking squarely toward the stem.

18. On the arrangement view, or elevation, show the plate seam and the edge of the plate on the stem at the scarf. These will be the same as the detail except they are at the reduced scale.

19. Next draw the Sections Throughout Lower Part of Stem, to a scale of $1\frac{1}{2}$ inches = 1 foot. This view consists of a profile of the casting, with cross-sections drawn at their proper places along the length of the casting. In order to get the whole length of the view onto the plate at the large scale, it is broken into two parts, the division being made between frames 1 and $1\frac{1}{4}$ shown in the elevation. Draw a light pencil line repre-

senting the base line of the ship $6\frac{7}{16}$ inches (actual distance) above the lower border; as this is only a temporary construction line it is not shown on the finished plan.

On the base line locate a point representing frame, or transverse, No. 1, 2 inches (actual distance) from the left-hand border line; also locate points for frames $\frac{3}{4}$ and $\frac{1}{2}$, 24 inches apart (to scale) to the right of frame 1 and from these points draw light vertical lines locating the frames. Then the location of the part of the bottom of the stem shown in the upper view is determined by laying off on these lines points at

OFFSETS FOR DRAWING SECTIONS OF FOREFOOT CASTING

	A	*B*	*C*	*D*	*E*
Frame	Half Siding Inches	Height Above Contour Inches	Half Widths Inches	Height Above Contour at Outer Edge Inches	Half Width to Outer Edge Inches
$\frac{1}{2}$	$1\frac{7}{16}$	7	$2\frac{7}{8}$	$14\frac{1}{4}$	$4\frac{1}{4}$
$\frac{3}{4}$	$1\frac{7}{16}$	4	$3\frac{7}{8}$	$8\frac{1}{2}$	$6\frac{3}{8}$
1	$1\frac{1}{2}$	3	$4\frac{7}{8}$	$5\frac{3}{4}$	$7\frac{5}{8}$
$1\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{2}$	$5\frac{5}{8}$	5	$8\frac{3}{4}$
$1\frac{1}{2}$	$3\frac{1}{2}$	$1\frac{1}{2}$	$6\frac{1}{2}$	$3\frac{3}{8}$	$10\frac{1}{4}$
After end of stem	4			$2\frac{3}{8}$	$11\frac{3}{8}$

distances above the base line as follows: At frame $\frac{1}{2}$, 5 feet $4\frac{1}{4}$ inches; at frame $\frac{3}{4}$, 4 feet $1\frac{3}{8}$ inches; at frame 1, 3 feet $4\frac{3}{8}$ inches, these distances being taken from the elevation, or arrangement drawing. That the shape of the bottom of the stem may be accurately defined, it is advisable to locate points intermediate between frames 1 and $\frac{3}{4}$ and between $\frac{3}{4}$ and $\frac{1}{2}$. These points are at horizontal distances of 12 inches each side of frame $\frac{3}{4}$, the point on the side toward frame $\frac{1}{2}$ being 4 feet $7\frac{1}{2}$ inches above the base line, and that toward 1 being 3 feet $8\frac{1}{2}$ inches.

When these points have all been located a solid line may be drawn through them with a ship curve and this line will be the contour line of the bottom of the stem in the upper view. Those parts of the frame lines that are to remain on the finished drawing may then be drawn as dot-and-dash lines.

20. Next, on frame $\frac{1}{2}$, locate a point $14\frac{1}{4}$ inches above the contour line of the bottom. The actual shape of the stem casting has to be taken from the Lines drawing of the ship, and in this case the offsets for constructing each of the six sections that are to be drawn are given in the accompanying table of Offsets for Drawing Sections of the Forefoot Casting.

The sections are taken perpendicular to the base line at the frames, and show the views that would be seen by a person looking aft. The frame line is the center of the section of which only one-half is shown. Fig. 2 shows the points at which the dimensions designated by the letters *A*, *B*, *C*, etc., in the table of offsets, were measured.

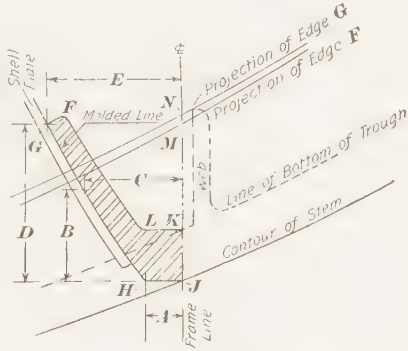


FIG. 2

Where the stem casting is wide enough, it is made trough-shaped, as at frame $\frac{3}{4}$ and aft. At frame $\frac{1}{2}$ the section of the ship is so narrow that it is not practical to make the stem trough-shaped, so it is made solid with a vertical depth of $14\frac{1}{4}$ inches. An idea of the general appearance of the casting is given by the perspective view, Fig. 3.

21. The method of drawing the sections will now be described and the various points will be identified by the letters marking similar points in Fig. 2. First, at the intersection of the contour line of the stem with frames $\frac{1}{2}$, $\frac{3}{4}$, and 1, draw horizontal lines, and on them, to the left of the frame line, lay off the half sidings *J H*, which, from column *A* in the table of offsets, are $1\frac{7}{16}$, $1\frac{7}{16}$, and $1\frac{1}{2}$ inches, respectively.

Next, above the horizontal lines just drawn, locate the point G by the measurements D and E. Also locate the intersection of measurements B and C and draw the line $G\,H$

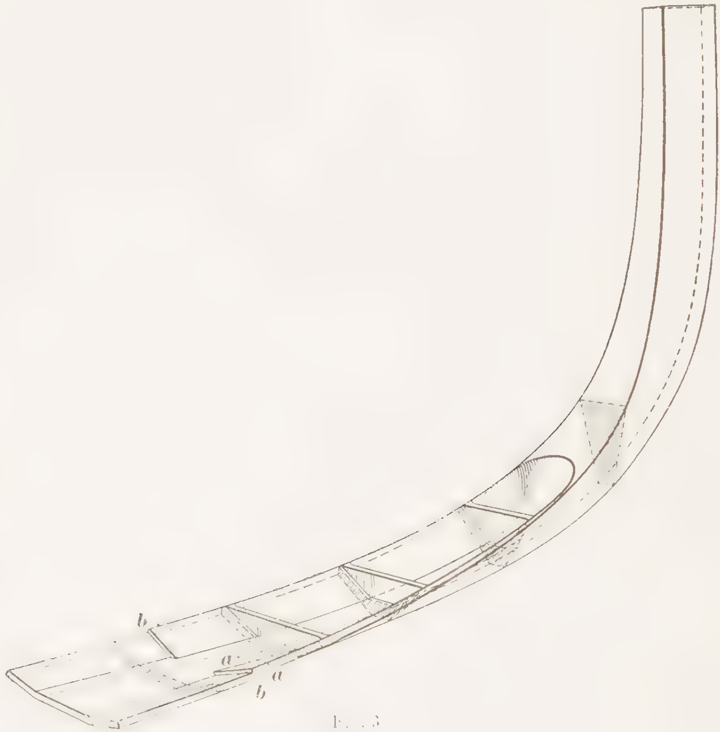


FIG. 3

curved to pass through this point of intersection. At frame $\frac{1}{2}$, $G\,H$ is a straight line drawn to intersect the half siding $J\,H$ previously mentioned.

At frames $\frac{3}{4}$ and 1, locate points K, 3 inches and $2\frac{3}{4}$ inches, respectively, from the contour line, the distance being measured on a line perpendicular to the contour of the stem and representing the thickness of the stem on the bottom. These points K are at the center line of the casting and the bottom of the trough. Draw horizontal lines, as $K\,L$, of indefinite length, representing the location of the bottom of the trough.

At $G\,F$ the thickness of the stem casting is shown on the plate to be 1 inch. Draw $G\,F$ perpendicular to $G\,H$ and round

off the corners, freehand. Then, measuring at right angles to $G H$ find a point on $K L$ that is $1\frac{1}{4}$ inches distant from $G H$; this will locate point L. Then draw $F L$ and round the connection between it and $K L$, freehand. Cross-hatch the section at frames $\frac{1}{2}$, $\frac{3}{4}$, and 1.

By light pencil lines, project points F and G horizontally to frames $\frac{3}{4}$ and 1, thus locating the points M and N on the upper contour of the stem. On this plate, the projection of the side of the section at frame $\frac{1}{2}$ is at the point $14\frac{1}{4}$ inches above the contour line. Through these projected points draw the lines marked *Projection of Edge F* and *Projection of Edge G* in Fig. 2. These are the lines seen when looking at the casting from the side, as in Fig. 3. These lines converge at a point 12 inches forward of frame $\frac{3}{4}$. With a radius of 12 inches and a center on frame $\frac{3}{4}$ at the same level as the point of convergence, draw in pencil an arc from the point of convergence on the upper contour toward the bottom of the trough. This is the forward end of the trough. Through points K in the sections at frames $\frac{3}{4}$ and 1, draw in pencil a line that will fair in to the arc just drawn. This line, shown dotted, is the bottom of the trough. In the casting are transverse webs .40 inch forward of frames $\frac{3}{4}$ and 1. The floors, which are .40 inch thick, but are not shown here, go between the frames and the web, and are riveted to both. The webs are 1 inch thick and have an arc of $\frac{3}{4}$-inch radius at the top and bottom on the forward side. Show webs and the bottom of the trough as a dotted line. These webs, shown also in Fig. 3, will be drawn later in the plan below the elevation in the arrangement view.

22. In the Detail of Riveting in Stem already drawn, the shell plating is shown to lap $7\frac{1}{2}$ inches on the stem. As the large sections are drawn through the frame line perpendicular to the contour of the stem, these sections do not show the true lap but only the projection of the lap. By descriptive geometry these projections can be drawn exact, but as it is not necessary to have them exactly to scale, approximations will do. The projections of the laps are to be drawn as 11 inches, 9 inches, and $7\frac{1}{2}$ inches at frames $\frac{1}{2}$, $\frac{3}{4}$, and 1, respectively. Aft of a

point a little forward of frame 1, the lap on the forefoot decreases, hence the projections at frames 1 and $1\frac{1}{4}$ show an actual lap of less than the $7\frac{1}{2}$ inches. The shell plating here is .46 inch thick. In this view show both the forward and the after ends of the stem broken off.

23. At a distance of $6\frac{3}{8}$ inches (actual measurement) above the lower border line, draw a pencil line, which will be the ship's base line for the sections at frames $1\frac{1}{4}$ and $1\frac{1}{2}$ and at the after end of the casting. Locate the after end of the casting $3\frac{1}{8}$ inches (actual measurement) from the left-hand border line. Frames $1\frac{1}{2}$ and $1\frac{1}{4}$ are spaced 18 inches and 21 inches forward of the after end of the forefoot casting. Locate the bottom of the forefoot casting 2 feet $2\frac{1}{4}$ inches, 2 feet $6\frac{1}{2}$ inches, and 2 feet $10\frac{3}{4}$ inches above the base line at the after end and at frames $1\frac{1}{2}$ and $1\frac{1}{4}$, respectively. The bottom is a straight line from the after end to a point 4 inches aft of frame $1\frac{1}{4}$. At that point there is a shoulder or rabbet .72 inch deep perpendicular to the contour line. The contour is continued to the point on the frame $1\frac{1}{4}$, but .72 inch below and parallel to the contour line aft of the shoulder. Extend the contour line 9 inches forward of frame $1\frac{1}{4}$ and curving slightly upward. This part is a continuation of the partial profile of the forefoot casting above, but as the sections are the essential parts of this portion of the drawing it is not of vital importance that this curve be exact. The profile can be seen in its entirety in the arrangement elevation in the lower right corner.

Draw the section at frame $1\frac{1}{4}$ and the web .40 inch forward of it, in the same manner as described for the preceding sections. The offsets for drawing these are shown in the table just given. The thickness of the bottom of the stem at frame $1\frac{1}{4}$ is $2\frac{1}{2}$ inches. The molded half siding, shown in the table for all the sections, is given on the plate for all except the after section and section at $1\frac{1}{2}$; in these the half siding of the casting is given to dimension the casting, and in all cases the distance from outer corner *H*, Fig. 2, to the top at *G* is dimensioned to fix the extent of the casting. The projection of the shell-plating lap is 7 inches.

For the after end of the casting and at frame $1\frac{1}{2}$, draw the half siding and the dotted frame line to dimensions given in the table. Parallel to these side lines and .46 inch below ($\frac{1}{2}$ inch will be as accurate as can be drawn) draw the side line of the casting; this line will extend down to the half-siding line continued, and up to a line perpendicular to the dotted frame line and drawn through the point in the dotted line located by dimensions *D* and *E*, Fig. 2. It will be noted that these two after sections show the sides of the stem casting to be .46 inch outside the frame line. Fig. 4, which is a sectional picture through the center line showing the connections between

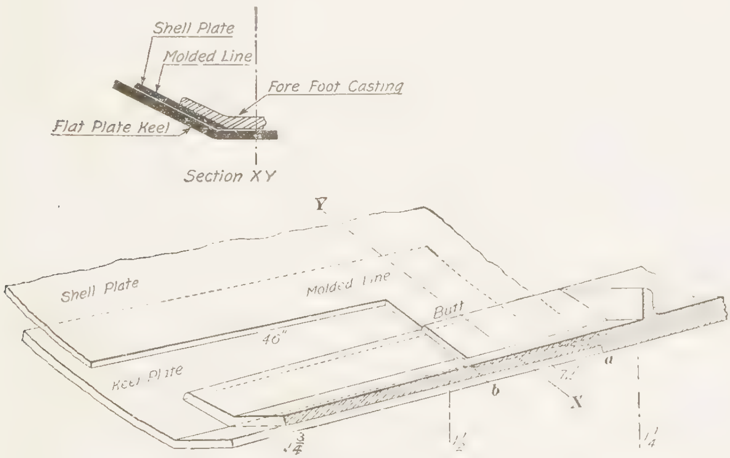


Fig. 4

the stem, flat keel, and shell, shows the reason for this. At *a* is the forward end of the keel plate 4 inches aft of frame $1\frac{1}{4}$. At this point, on the bottom of the casting, is the .72-inch rabbet shown in the plate. At *b*, which is the point shown on the plate $10\frac{1}{2}$ inches aft of the shoulder, is the after end of the butt at the forward end of the keel. Forward of *a* the shell plate laps directly on the stem as shown in sections at frames $\frac{1}{2}$, $\frac{3}{4}$, 1, and $1\frac{1}{4}$. In these, the outer face of the stem casting is the molded line. Between *a* and *b* the shell plate laps onto the stem, and the flat-plate keel wraps around the stem outside the shell plate, as shown in Fig. 4.

The molded line of the vessel is inside the shell plate. The keel is an outside strake located as shown in Fig. 4 and is a smooth fair plate without joggles, extending as far forward as the keel shoulder at *a*. Aft of point *b*, which is $10\frac{1}{2}$ inches aft of *a*, if the side of the stem were continued in a fair plane as forward of *b*, there would be a space between the keel and the stem equal to the thickness of the shell plate. To fill up this space the stem casting is joggled outwards aft of point *b*, but on the sides only, and this joggle is equal to the thickness of the shell plate, which is .46 inch. This is shown also forward of frame $1\frac{1}{2}$ in the plan of the casting below the arrangement view of the stem.

Accordingly, the sections of the casting at frame $1\frac{1}{2}$ and at the after end are drawn similarly to the other sections, the dimension .46 inch being the joggle from the molded line to bring the casting down to the top of the keel. The thicknesses 1 inch and $1\frac{1}{4}$ inches are measured from the face of the casting. The thickness of the bottom of the stem at frame $1\frac{1}{2}$ is $1\frac{1}{2}$ inches. In actual practice, the line of the bottom of the trough is drawn a fair curve from the after end to the thickness selected at frame $\frac{3}{4}$, and intermediate thicknesses are scaled from this line. But as the elevation is here given in two parts the thicknesses at the intermediate frames are given to facilitate drawing.

Draw the full line perpendicular to the contour of the stem and $10\frac{1}{2}$ inches aft of the shoulder. This is the line of the joggle shown in the profile. The projections of the upper and lower outer edges of the flange (points *F* and *G* in Fig. 2) are drawn similar to those in the upper part, except that a jog is shown to indicate the joggle in the sides. Note that the bottom of the casting is without any joggle at this point, as shown in Section *X Y* in Fig. 4. There is a rounded corner at the after end of the casting which may be drawn freehand. Forward of frame $1\frac{1}{2}$ the casting is shown broken off.

The riveting note just aft of frame $1\frac{1}{4}$ shows the difference in size of rivets in the .72-inch keel plate and the .46-inch shell plate. See the last note under Table I, *Ship Drafting*, Part 2. The center line vertical keel, drawn in Plate 1053, extends to

frame $1\frac{1}{4}$ and the bottom angles are riveted to the forefoot casting.

The lower part of the elevation of the stem in the arrangement drawing may now be finished, and it is a duplicate of the larger profile above, except that only one line is drawn to show the top of the flange. Note here that, aft of the shoulder 4 inches aft of frame $1\frac{1}{4}$, the contour of the stem casting lies on the rise line of the stem.

24. The plan of the stem is next to be drawn. Draw the horizontal center line $\frac{7}{8}$ inch, actual distance, above the lower border. From the profile, project the frames and the extreme ends of the casting. Mark on each frame line the distance of the outer edge of the flange, as point *G*, Fig. 2, from the center line, these to be scaled from the sections just drawn. Draw a full line through these points on each side of the center line, and forward of frame $\frac{3}{4}$ fair this in to the half siding of the bar stem, $1\frac{7}{16}$ inches. Show the joggle in the flange between frames $1\frac{1}{4}$ and $1\frac{1}{2}$. The $1\frac{7}{16}$-inch half-siding dimension holds from the top of the stem to below the scarf. Locate the forward end of the trough 12 inches forward of frame $\frac{3}{4}$ and show it ending in a semicircle of $4\frac{1}{2}$-inch radius. Show the projection of the inner edge of the flange, the projected thickness decreasing toward the after end as the flange flattens and the top and bottom more nearly coincide. As this is more of a picture than a working view the thickness may, for the sake of clearness, be drawn a little larger than actual, or about 2 inches. Draw the transverse webs, showing a fillet in the corners where they join the side flanges of the casting. These webs give transverse strength to the casting and also furnish an attachment for the floors.

The half siding of the bottom of the casting is drawn dotted. The cross line 4 inches aft of frame $1\frac{1}{4}$ is the shoulder, the flaring sides of the casting making the half siding greater aft than forward of it. A transverse full line $10\frac{1}{2}$ inches aft of the extreme forward end of the stem shows the projection of the extreme top. The lettering, the schedule of material, and the title complete the drawing.

STERN FRAME AND RUDDER

25. Plate 1060 shows the arrangement of a stern frame and rudder with some details; Plate 1061 shows other details of the same parts. The views on these two plates are so closely related that one will often help to an understanding of the

Fig. 5

other, and in drawing one plate it will often be necessary to get details and dimensions from the other. They will therefore be described together. Directions for making the drawings will be given separately so far as possible, but, as will be explained

at the proper place, some of the parts on Plate 1060 can be better understood after the details of those parts are drawn on Plate 1061; therefore, both of these plates should be completed before either is sent in for correction.

The stern frame, like the stem, forms a connection between the two sides of the vessel; it also provides a support for the rudder, and in single-screw steamers it supports the propeller and forms the opening in which the propeller is located.

The stern frames shown in Plate 1060 and Fig. 5 are those used for ordinary single-screw steamers. The forward upright part is called the **propeller post,** since it has the boss, or enlargement, through which the propeller shaft passes, the propeller being mounted on this shaft immediately behind this post. The after upright part is the **rudder post,** so called from its being the rigid part on which the rudder is hung. The connection between the rudder post and the propeller post at the bottom is called the **shoe** and the connection at the top is the **arch.** The space within these four parts is known as the **propeller aperture** since the propeller revolves within it.

In twin-screw steamers there is no propeller post, as the propellers are at the sides of the vessel, as shown in Fig. 6. The vessel there shown has a special type of rudder and hence no stern frame. But in twin-screw vessels having the ordinary type of rudder, the stern frame consists of the rudder post and a projection forward from the bottom that attaches the post to the keel.

26. The **rudder** is the device by which the vessel is steered, and in most vessels of today it is operated through a steam engine by controlling gear located on the navigating bridge and perhaps at one or two other convenient places. A hand gear is always provided to be used in case the steam gear is disabled. The rudder is usually allowed to swing about 35 degrees each side of the center line, the motion being transmitted through a horizontal lever or *tiller,* to use the marine term, or through a quadrant rigidly secured to the rudder shaft, or stock, and to which the blade is attached. The pins on which the rudder swings are called *pintles,* piece **6** on the plate.

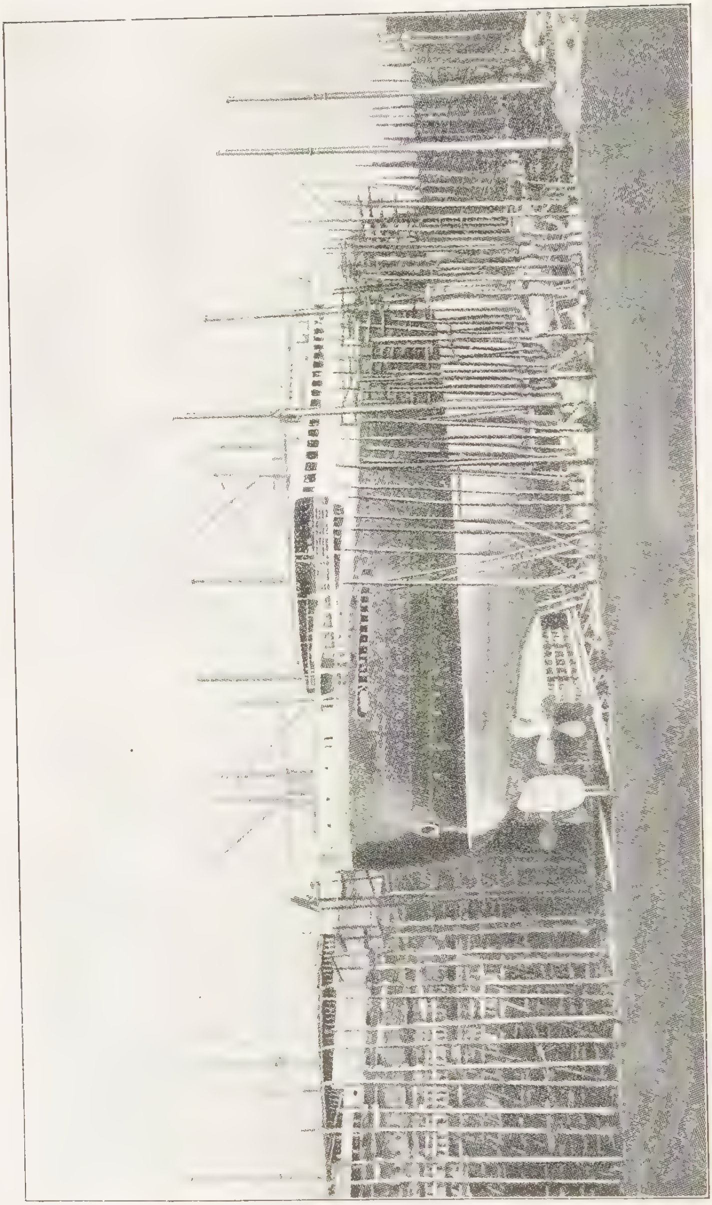


Fig. 6

The plate blade of the rudder here shown is held in a rudder frame, piece **4**, on which the pintles are mounted. The frame is connected through a coupling, horizontal in this case, to the stock, piece **3**.

The rudder is prevented from turning beyond its allowable amount by stops on the deck, or elsewhere, limiting the movement of the quadrant or tiller, or by cheeks forged or cast on the stern frame and rudder frame, which come in contact when the limiting angle of travel is reached. Usually an automatic device cuts off the supply of steam to the steering engine at 2 or 3 degrees before the positive stops would come in contact. The center lines of the pintles and the rudder stock must coincide in order to have any movement of the rudder.

The diameter of the rudder stock depends on the area and center of gravity of the surface of the rudder and also on the speed of the vessel.

27. The type of rudder shown in Plate 1060 and in Fig. 5 is called a single-plate rudder. The plate blade is supported by arms situated alternately on either side; those shown on Plate 1060 are cast integral with the main part of the frame. The arms are sometimes made separate and secured to the frame by keys, or they may be shrunk on as those in Fig. 5. In a double-plate rudder, the arms are in the center and are cast with the main part; this casting also includes a *bow* which connects the after ends of the arms and makes the contour of the rudder. On each side is a covering plate. This, of course, makes a thicker blade than the single-plate type and also gives a smooth-sided blade. The space between the arms, bow, and plate is filled with wood. The frames of rudders and also the stocks may be of cast or wrought steel or of wrought iron. Sometimes the blade and frame are made one, in which case cast steel is the material.

In Fig. 5 the different parts of the rudder and stern frame are lettered and their names are given in the following list:

a Rudder stock extending from coupling *b* up into the ship and through which the motion of the steering engine above is transmitted to the rudder.

b Coupling of *a* and *f*. Round flanges on each are bolted and keyed together.

f Main piece of the rudder frame with a coupling flange at the top. In Plate 1060 the arms, here marked *e*, are cast in one piece with *f*. As shown in Fig. 5, the arms *e* are separate and are shrunk on; *f* is sometimes called the stock.

g Rudder plate or blade.

e Arms, five in all, alternated on the two sides of the plate *g* and swelled out around *f* at *d* where they are shrunk on the main piece *f*. The extreme forward part of the arm beyond *d* is the *pintle lug*.

h Part of the stern frame called the rudder post and on which the gudgeons are cast.

c Rudder gudgeons supporting the pintles, or hinge pins, on which the rudder swings. The pintles are fast in the pintle lugs and swing in holes in *c*.

l Part of the stern frame called the propeller post.

m Part of the stern frame called the shoe. It connects *l* and *h*.

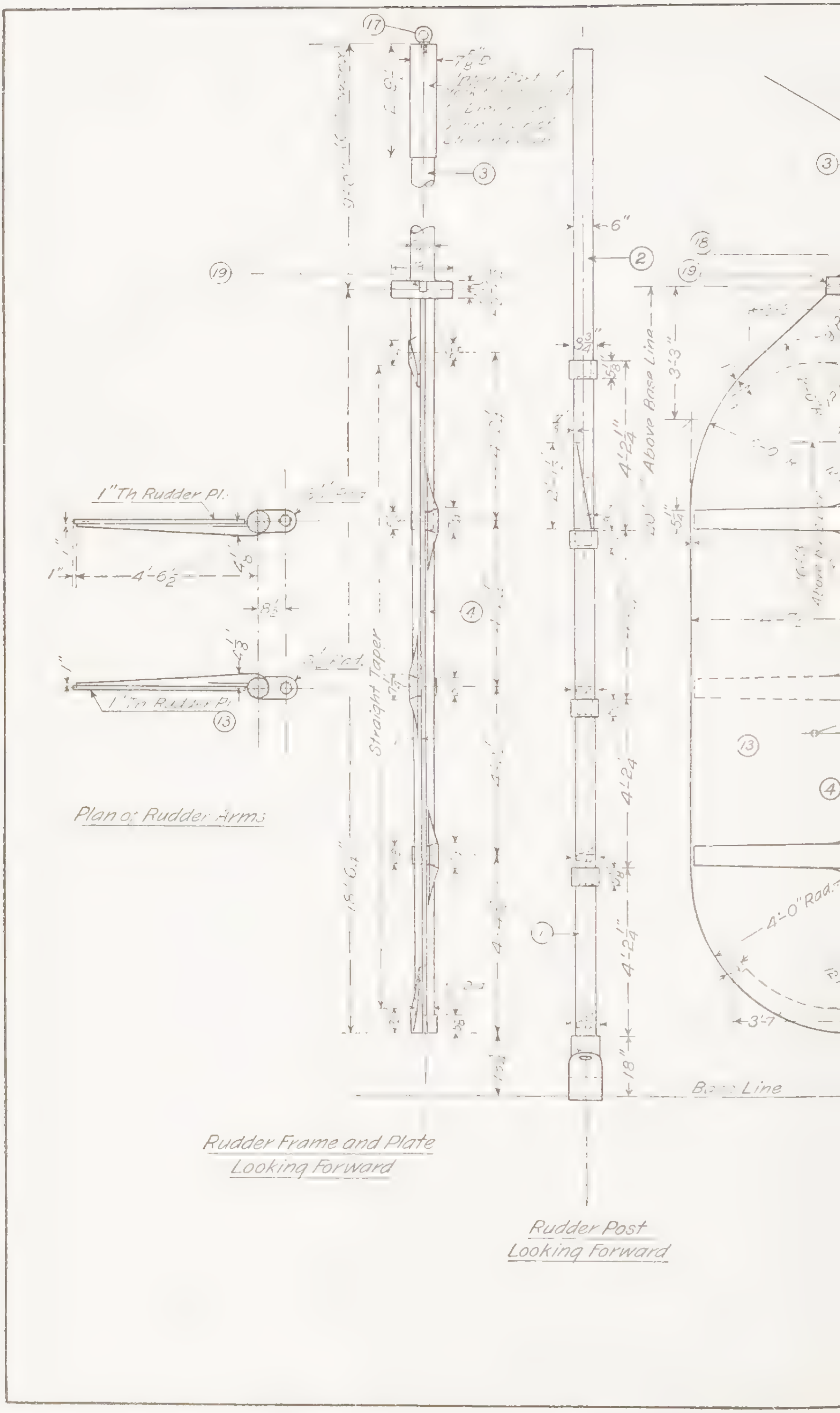
j Hub of the propeller, to which the blades are rigidly attached.

k Sometimes *j* and *k* are cast together and at other times, as here shown, the blades *k* are bolted to *j*.

n Part of hull called the counter.

Parts *a*, *e*, *f*, and *g* are rigidly secured together and turn as one piece.

28. Fig. 6 shows what is known as a balanced rudder. The stock is attached to the blade about one-third of the length of the rudder aft of the rudder's forward end and is supported at the point where it passes through the shell of the vessel. There are no pintles in this type of rudder. This type is not adapted for single-screw vessels; the vessel here shown has twin screws or propellers. This vessel has what is called a *cruiser stern* from the fact that it is like a warship and has no overhang aft of the end of the load water-line.


1"Th Rudder Pl.
Plan of Rudder Arms
Straight Taper
Above Base Line
4'-0" Rad.
Rudder Frame and Plate
Looking Forward
Rudder Post
Looking Forward

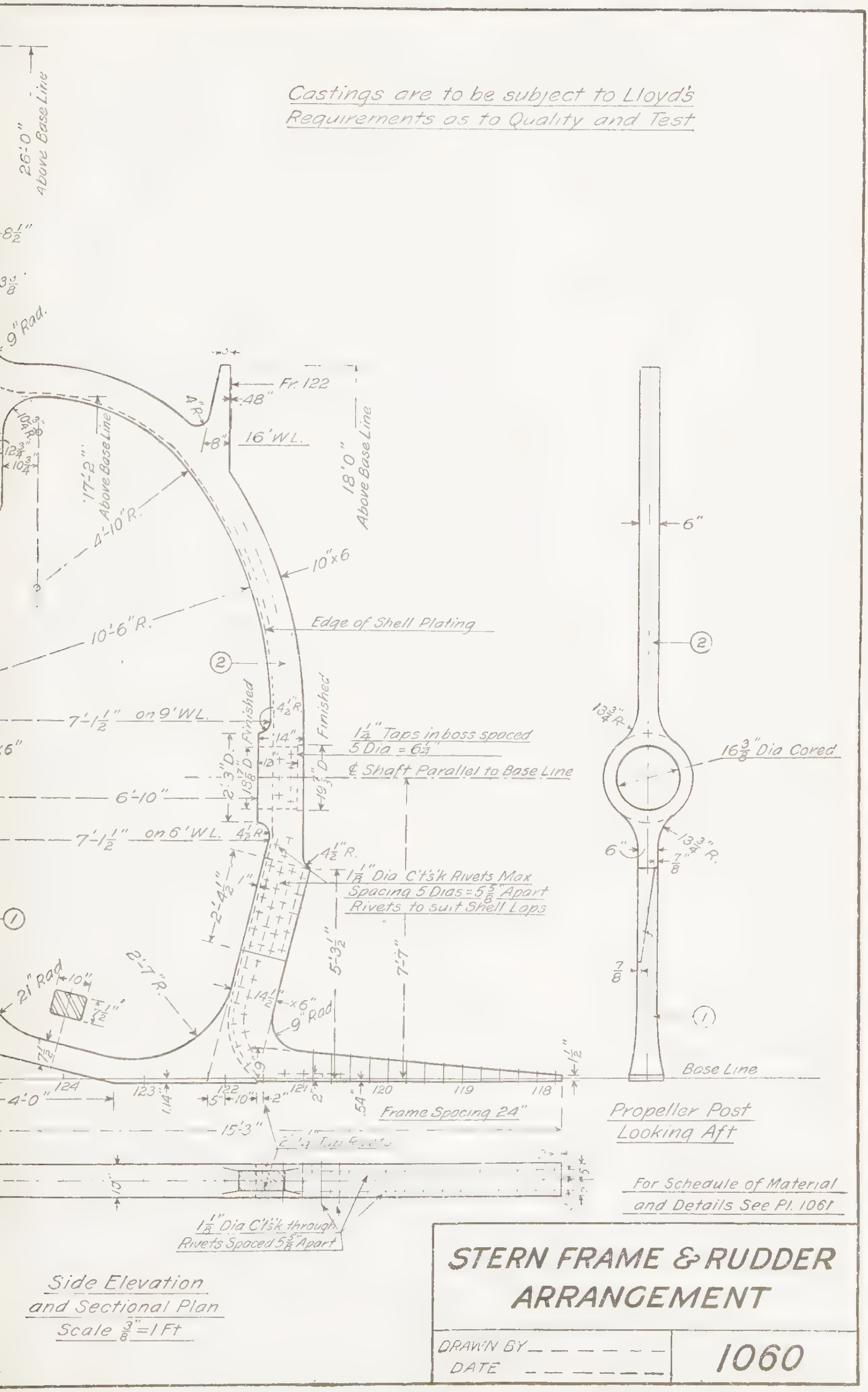

Castings are to be subject to Lloyd's Requirements as to Quality and Test
Edge of Shell Plating
Finished
$1\frac{1}{4}$" Taps in boss spaced 5 Dia = $6\frac{1}{4}$"
℄ Shaft Parallel to Base Line
$1\frac{1}{8}$" Dia C'ts'k Rivets Max Spacing 5 Dias = $5\frac{5}{8}$" Apart
Rivets to suit Shell Laps
Frame Spacing 24"
Base Line
$16\frac{3}{8}$" Dia Cored
Propeller Post Looking Aft
$1\frac{1}{8}$" Dia C'ts'k through Rivets Spaced $5\frac{5}{8}$" Apart
Side Elevation and Sectional Plan Scale $\frac{3}{8}$" = 1 Ft
For Schedule of Material and Details See Pl. 1061
STERN FRAME & RUDDER ARRANGEMENT
DRAWN BY
DATE
1060

PLATE 1060, TITLE: STERN FRAME AND RUDDER ARRANGEMENT

29. The stern frame and rudder shown on Plate 1060 are for a vessel about 300 feet long. The scale is to be $\frac{3}{8}$ inch $=1$ foot.

Draw the molded base line $2\frac{7}{8}$ inches, actual measurement, above the lower border. At a distance of $8\frac{1}{2}$ inches from the left-hand border, draw the after perpendicular, which is the after side of the rudder post. On the base line locate frame *125* at a distance of 9 inches, to scale, forward of the after perpendicular *A. P.*, and frames *124* to *118*, spaced 24 inches apart, should be ticked in.

At a distance of 16 feet 3 inches above the base line is the top of the scarf that connects the pieces **1** and **2** of the stern frame. Draw the outline of this part of the rudder post, to the scale here used, from dimensions given in Detail of Scarf and Rudder Post on Plate 1061. Draw a light horizontal pencil line 17 feet 2 inches above the base line and extending forward from the rudder post. With a radius of $10\frac{3}{4}$ inches draw an arc tangent to this line and the forward side of the scarf continued upwards. Locate the top of the stern frame 26 feet above the base line. The rudder post is $8\frac{1}{2}$ inches fore and aft by 6 inches wide. Extend this section down 7 feet 3 inches from the top. At a distance of 10 inches above the 17-feet 2-inch horizontal line previously drawn, draw a light horizontal pencil line. With an arc having a 9-inch radius, connect this line with the forward side of the top of the rudder post. This locates the top of the arch, the lower side of which fixes the upper limit of the propeller aperture. The size of the aperture is naturally controlled by the diameter of the propeller and the clearance between the tips of the blades and the hull.

30. Draw the forward side of the rudder post $8\frac{1}{2}$ inches forward of the after perpendicular and continuing down from the scarf to about 30 inches above the base line.

Draw a vertical dot-and-dash line $4\frac{1}{4}$ inches aft of the after perpendicular to represent the center line of the pintles and the stock.

From the Detail of Intermediate Pintles, on Plate 1061, it is seen that the gudgeons or pintle supports on the rudder post have a radius of $4\frac{3}{8}$ inches about the center line of the pintles. In the arrangement drawing, locate the lower gudgeon 13 inches above the base line at its after side and extending $4\frac{3}{8}$ inches aft of the center line. The lower gudgeon is 5 inches deep. Locate the tops of the other four gudgeons 4 feet $2\frac{1}{4}$ inches apart, these being $5\frac{1}{8}$ inches deep as shown in the view at the left, entitled Rudder Post Looking Forward. Now the gudgeons can be drawn except the bottom of the lower one. The detail on Plate 1061 shows an arc of $1\frac{1}{4}$-inch radius to be used where the gudgeon joins the rudder post and an arc of $\frac{3}{4}$-inch radius at the top and bottom about the gudgeon. As these are almost too small to draw with a bow pen, it is permissible in this drawing to put them in, at least the $\frac{3}{4}$-inch radius, freehand with a writing pen.

The lowest part of the stern frame is 1.14 inches below the base line. On the base line, locate a point on the stern frame 4 feet forward of the after perpendicular and draw the bottom of the stern frame, or shoe, as a straight line from this point to the after lower edge of the lowest gudgeon. Draw a light pencil line parallel to this line and $7\frac{1}{2}$ inches above. With a radius of 21 inches, draw an arc tangent to this upper line and the forward edge of the rudder post.

Continue the lowest line of the stern post, which is 1.14 inches below the base line, forward to a point 10 inches forward of frame *122*. At this point there is a rabbet of .60 inch to take the flat plate keel which is .60 inch thick and is thus flush with the stern post. The horizontal part of the stern frame is continued forward, .54 inch below the base line, to a point 15 feet 3 inches forward of the after perpendicular. This projection forward of the propeller post is necessary in order to get a satisfactory connection to the structural part of the hull; at the forward end, this part of the stern frame is $1\frac{1}{2}$ inches deep.

31. The fore-and-aft length of the aperture depends upon the size of the propeller hub and whether it is to be possible to remove the propeller from the propeller shaft by simply sliding it aft and taking it out from between the end of the shaft and the rudder post, or whether the shaft must be drawn forward to permit the propeller to be taken out. In the frame shown in Plate 1060, it is possible to use the first method. The aperture is 6 feet 10 inches between the forward side of the rudder post and the after face of the boss, or enlargement, of the propeller post through which the propeller shaft passes. Draw a dot-and-dash line representing the center line of the shaft 7 feet 7 inches above, and parallel to, the base line. Draw the straight vertical line for the after face of the boss 2 feet 3 inches long and with its center on the center line of the shaft. Locate a point on the 6-foot water-line 7 feet $1\frac{1}{2}$ inches forward of the rudder post and also a point on the base line 5 inches aft of frame *122*. Connect these by a light pencil line which locates the after side of the propeller post. With a radius of $4\frac{1}{2}$ inches, draw an arc tangent to this line and meeting the lower face of the boss.

With a radius of 2 feet 7 inches, draw an arc tangent to the top of the shoe and the after side of the lower part of the propeller post. Draw another pencil line parallel to and $14\frac{1}{2}$ inches forward of the after side of the propeller post, and from a point on this line 9 inches above the base line draw a pencil line to the top of the forward end of the shoe. With a radius of 9 inches, draw an arc tangent to this line and the lower forward side of the propeller post.

32. Draw a vertical line 14 inches forward of the after face of the shaft boss, and with a radius of $4\frac{1}{2}$ inches, draw an arc tangent to this line and through a point on the forward side of the propeller post 5 feet $3\frac{1}{2}$ inches above the base line. This point is the upper forward corner of a scarf extending 2 feet $4\frac{1}{2}$ inches downwards. The scarf ends are perpendicular to the sides of this part of the propeller post. The lower end is shown by a full line and the upper end dotted, which indicates that the upper part of the stern frame is on the near side and

the lower part on the far side. A cast stern post of this size is better to be made in two pieces, but if forged it could be made in one piece.

33. At the 9-foot water-line the after side of the propeller post is 7 feet $1\frac{1}{2}$ inches forward of the forward side of the rudder post. With a radius of $4\frac{1}{2}$ inches, draw an arc tangent to a vertical line through this point, the arc passing through the top of the after face of the boss. With the center on the 9-foot water-line and a radius of 10 feet 6 inches, draw an arc outlining part of the after side of the propeller post. With its center on a line $10\frac{3}{4}$ inches forward of the forward side of the rudder-post scarf, draw an arc tangent to the one just drawn and tangent to the top of the arch. The radius will be about 4 feet 10 inches. Draw the forward side and top of the propeller post and arch by drawing arcs with the same center as the above but with 10 inches more radius.

34. At a point .48 inch aft of frame *122* is the forward side of a horn or vertical projection from the arch of the stern frame. This horn is attached to a floor plate on this frame, the floor being .48 inch thick. Of course, .48 inch will be drawn as $\frac{1}{2}$ inch. The horn extends to a point 18 feet above the base line and is 3 inches wide fore and aft at the top. The back slopes toward a point 8 inches aft of the front on the 16-foot water-line. The back of the horn and top of the arch are connected by an arc of 4-inch radius. Show a dash line indicating frame *122*.

35. In the Detail of Intermediate Pintles, on Plate 1061, note that the pintle, piece **6**, is covered by the composition bushing, piece **8**, which is fastened to piece **6** by the machine screw, piece **12**. The pintle and bushing turn in the bushing, piece **9**, which is set into the gudgeon on the stern post. The outside diameter of this latter bushing is $5\frac{1}{2}$ inches and it rests on a shoulder $\frac{1}{2}$ inch from the bottom. In the Detail of Lower Gudgeon the shoulder on which piece **9** rests is dimensioned $4\frac{5}{8}$ inches from the top. This checks with the $\frac{1}{2}$ inch from the bottom in the others, the total depth of the gudgeons, except the bottom one, being $5\frac{1}{8}$ inches.

Therefore, in drawing the stern frame show dotted the holes in the gudgeons for the pintle bushings—$5\frac{1}{2}$ inches in diameter for $4\frac{5}{8}$ inches from the top and $4\frac{1}{2}$ inches diameter at the bottom. The centers of these holes are, of course, on the center line of the pintles. Through a point on the after side of the rudder post 22 feet 11 inches above the base line, draw a line upwards from the forward side of the post and at an angle of 60 degrees with the post. This line is the under side of the overhang, or counter, as the part of the hull aft of and above the stern frame is often called. See Fig. 5 at *n*.

From this line to the rabbet in the bottom of the stern frame there is a dotted line which represents the edge of the shell-plating lap on the stern frame. Along the top of the rudder post and along the arch and down the propeller post, this line is 1 inch forward of the edge of the frame; at the junction of the arch and the rudder post it is an arc with a radius of $16\frac{1}{2}$ inches, the center of which is $1\frac{1}{2}$ inches below the center of the 9-inch radius of the inner or forward side of the frame. Across the boss this edge continues as a straight vertical line; at the bottom of the propeller post it follows an arc passing through the top of the rabbet and tangent to the edge line on the lower propeller post and having a radius of $22\frac{1}{2}$ inches. This radius is chosen such that it will be equal to the lap of the plating on the propeller post ($14\frac{1}{2}'' - 1'' = 13\frac{1}{2}$ inches) plus the radius at the inner side of the propeller post.

Concentric with the center line of the shaft, draw dotted the bores for the stern tube in the boss. The cast-iron stern tube contains the bearings for the propeller shaft. For 12 inches from the after face of the boss this is $18\frac{7}{8}$ inches finished diameter, and at the forward face of the boss it is $19\frac{7}{8}$ inches finished diameter. With the exception of rivet lines and dimensions, the stern-post part of this view is now complete.

36. At a point 2 inches, actual measurement, from the right-hand border, draw the center line of the elevation marked Propeller Post Looking Aft. This view shows the flare of the propeller post where it merges into the shoe, and also shows the propeller boss. This post is generally 10 inches fore

and aft and 6 inches wide. Draw two pencil lines 3 inches each side of the center line. Continue these to the top of the horn, 18 feet above the base line, and connect the lines at the top. At the center line of the shaft, projected from the other view, draw two circles in full lines representing the finished holes bored in the boss, the hole at the after end being $18\frac{7}{8}$ inches diameter and the counterbore 2 inches deep at the forward end and $19\frac{7}{8}$ inches in diameter. On the sample plate these two circles run together forming a heavy line, but they can be shown separate on the drawing. The counterbore gives the stern tube a fore-and-aft support. When the stern post is cast, the hole in the boss is cored $16\frac{3}{8}$ inches in diameter, as dimensioned, and after it is erected in place on the ship the finished borings are made. The outside diameter of the boss is shown by the outer circle, which is 2 feet 3 inches diameter.

The boss merges into the $10'' \times 6''$ part above and below by arcs of $13\frac{3}{4}$-inch radii tangent to the boss circle and the parallel sides of the post above and below. The dotted circle indicates the edge of the boss at the after end where it projects beyond the main portion of the post. Project over from the elevation of the propeller post the line 5 feet $3\frac{1}{2}$ inches above the base where the arc of $4\frac{1}{2}$-inch radius meets the forward side. The top of the scarf is also in this line. Project over the lower line of the scarf. The length of the scarf will not be shown in its true length in this view, as the scarf is at an angle with the vertical. The thickness of the ends of the scarf is shown as $\frac{7}{8}$ inch. As the top of the lower part of the propeller post, piece **1**, is shown on the far side of the side elevation, it will be shown in the right-hand side of the end elevation. Draw the diagonal line between the two ends, noting that this surface is finished and marked with the designating *f*. From points 20 inches above the base line, continue the side lines flaring out to the 10-inch width of shoe, or the bottom part of the stern frame, as is also shown in the plan view under the side elevation. The bottom of the propeller post is .54 inch (drawn $\frac{1}{2}$ inch) below the base line, and the top of the forward end of the stern frame is $1\frac{1}{2}$ inches above the bottom. This forward end is represented by the two horizontal lines.

37. Draw the center line of the plan view $\frac{15}{16}$ inch, actual distance, below the molded base line of the elevation. This view shows the width of the shoe and the forward projection of the stern frame into the hull. Mark the after perpendicular and frames on the center line. Draw the side lines 5 inches each side of the center line and let them extend parallel to each other from the forward end to a point 15 inches forward of the after perpendicular, from which point they fair in to the sides of the lower gudgeon referred to a little later. Project in dotted line the rabbet 10 inches forward of frame *122*. At the after perpendicular the post is 6 inches wide. Draw the cross-hatched section of the rudder post $8\frac{1}{2}$ inches long forward from the after perpendicular and 6 inches wide. From the forward corners of this rectangle draw diagonal lines 5 inches long extending toward the sides of the shoe. These indicate to the patternmaker about the distance in which he must swell out the casting from 6 inches to 10 inches width. Locate the center line of the rudder stock $4\frac{1}{4}$ inches aft of the after perpendicular. The projection of the lower gudgeon is the same as that of the intermediate gudgeons shown in Detail of Intermediate Pintles, on Plate 1061. With the center of the pintles as a center, draw an arc with a radius of $4\frac{3}{8}$ inches and connect this to the main post by fillets having a radius of 3 inches and tangent to the larger arc and to the sides of the rectangle. The small whole circles with their center at the center line of pintles represent the $4\frac{1}{2}$-inch-diameter bore and $5\frac{1}{2}$-inch-diameter counterbore in the gudgeon, as shown in the side elevation. Project down on the plan a cross-section of the propeller post perpendicular to it and at the lower end of the scarf. This will be the true width, 6 inches, but not the true length. This section is cross-hatched to indicate cast steel. From all the corners of this section draw diagonal lines 6 inches long toward the sides of the shoe to indicate in a general manner the shape or type of casting. The exact cross-section shape for the forward projection of the stern frame should be obtained from the mold loft to insure a fair surface with the after frames. This information, obtained by templets, enables the patternmaker to shape the forward end correctly.

38. The flat keel plate is attached to the forward-projecting part of the stern frame by a line of vertical rivets $1\frac{1}{4}$ inches in diameter on each of the center lines. These rivets are 3 inches from the center line, the forward rivets being 2 inches from the end. These rivets are spaced $5\frac{5}{8}$ inches apart, and there are fourteen pair, the after pair being $2\frac{7}{8}$ inches forward of frame *121*. Show these in the elevation by fine full lines at the proper spacing and extending through the casting. In the plan they are indicated by the small ticks on the rivet lines. At a distance of 2 inches from the after end of the keel plate and 3 inches each side of the center line, are located two $1\frac{1}{4}$-inch tap rivets. These are threaded and similar to bolts. When these are turned into the tapped holes as far as they will go, the head is chipped off. In this case their purpose is to hold the end of the plate firmly in place to enable the end to be caulked, and to hold the caulking after it is done. The keel plate is further secured to this part of the casting by four horizontal $1\frac{1}{8}$-inch through rivets $5\frac{3}{8}$ inches apart, 2 inches above the bottom of the casting. These are a continuation of the row down the propeller post and although shown here with the third from the front at frame *121*, these are located on the casting by the patternmaker or in the mold loft. Draw the $1\frac{1}{4}$-inch tap rivets in the elevation centered 2 inches forward of the rabbet and 2 inches above the bottom of the casting.

39. The end elevation of the Rudder Post Looking Forward is next drawn with its center line $5\frac{3}{8}$ inches from the left-hand border. Draw the sides 3 inches, to scale, each side of the center line and extending from a point 18 inches above the base line to the top, 26 feet above the base line. The point 18 inches above the base line is the top of the lower gudgeon. These side lines will be dotted where they are hidden by the projection of the rudder gudgeons. These gudgeons are 4 feet $2\frac{1}{4}$ inches apart, measured from the top of one to the top of the other, and are $5\frac{1}{8}$ inches deep. In the Detail of Intermediate Pintles, on Plate 1061, the radius of the gudgeon is marked $4\frac{3}{8}$ inches. Hence the end view will be $8\frac{3}{4}$ inches wide centered on the center line of the pintles. The drawing of the

holes in the gudgeons will be the same as in the side elevation. Project on the scarf and show its ends $\frac{7}{8}$ inch thick.

The width of $8\frac{3}{4}$ inches is continued for the depth of the lower gudgeon, which is 5 inches at the after end and more at the forward part on account of the downward slope of the bottom. From this parallel $8\frac{3}{4}$-inch part, the sides of the elevation spread out to a width of 5 inches each side the center line. Draw these side lines 5 inches each side the center line and extending 1.14 inches (draw 1 inch) below the base line.

It is necessary next to find the height at which this 5-inch half width appears on the end elevation. The after end of the 5-inch half width was given in the plan as 15 inches forward of the after perpendicular. Project this point up to the sloping line of the bottom of the shoe in the side elevation and from there project this height to the end elevation. This will be found to be 7 inches above the base line. Draw curves tangent to the side lines at this height and cutting the center line at the height of the after end of the gudgeon; these curves represent the swell of the sides joining the thickness at the gudgeon to the wider part of the shoe forward.

The upper side of the shoe at its lowest point is projected from the side view and is represented on the end view by a dotted line. Draw the hole in the gudgeon showing the opening at the bottom as an ellipse, it being the projection of the intersection of a circle and an inclined plane.

Next, on the side elevation, draw the cross-section of the shoe taken at a point $\frac{15}{16}$ inch, actual distance, measured along the slope of the shoe from the after perpendicular. Draw a dash line perpendicular to the bottom of the shoe, and $\frac{1}{4}$ inch, actual measurement, from the top of the shoe draw the cross-section of the shoe perpendicular to the dash line. Make the corners very slightly rounded and cross-hatch for cast steel.

40. Next draw the rudder on the side elevation, taking from details on Plate 1061 any dimensions not otherwise shown. In actual practice, these dimensions would be known in advance, so the detail drawings are really developments of the general plan instead of the general plan being developed from the

details. Many of the sizes of the parts are fixed by the classification society rules and vary for different diameters of stock. The rudder stock is the standard from which other parts of the rudder are determined. It is more convenient to show some of these dimensions on the detail drawings than on the general, or assembly, drawing.

First draw a horizontal pencil line 20 feet 1 inch, to scale, above the base line. This is the line of the joint between the stock, piece **3**, and the rudder frame, piece **4**. Draw the dot-and-dash center line of the main piece of the rudder frame $8\frac{1}{2}$ inches aft of the center line of the rudder stock and pintles. In the Detail of Rudder Stock Coupling and Upper Pintle, on Plate 1061, the diameter of the top part of this main piece is seen to be $7\frac{1}{4}$ inches. Accordingly, locate the forward ends of the flanges of pieces **3** and **4**, $3\frac{5}{8}$ inches forward of the center line of the main piece. From the same detail, the diameter of the coupling flanges is found to be 18 inches and the thickness $2\frac{1}{2}$ inches. Draw the flanges to these dimensions. Draw the two dotted lines—one $\frac{1}{2}$ inch above and one $\frac{1}{2}$ inch below the joint line—to indicate the top and bottom of the key, which, with the bolts shown in the detail, secures the stock of the rudder frame; the bolts need not be shown on this view. Draw the vertical dotted line 1 inch forward of the after edge of the coupling and extending up from the lower horizontal dotted line. This is the keeper, or retaining key, for the coupling shown as piece **19**, in the detail on Plate 1061.

41. Draw the cylindrical part of the stock, piece **3**, extending above and below the counter line and broken at the top. The stock is $7\frac{1}{4}$ inches in diameter and its center line is, of course, identical with the center line of the pintles. Above the joint between rudder and stock, with radii as shown in the detail on Plate 1061, and located as there shown, draw arcs tangent to the forward and after sides of the stock. These arcs are continued to the coupling flange on the stock. Cross-hatch the break of the stock at the top for cast steel.

42. Locate the bottom of the rudder frame $18\frac{3}{4}$ inches above the base line, thus leaving a space of $\frac{3}{4}$ inch between the

pintle and gudgeon. The same distance is allowed between other gudgeons and pintle lugs. In the view marked Rudder Frame and Plate Looking Forward, it will be seen that the five pintle lugs are each $5\frac{1}{8}$ inches deep. It is more convenient to put several of the dimensions for the rudder on this end view than on the side elevation, therefore some of the required dimensions may be taken from that view. The arms, which, alternating on the two sides, project aft from the main piece and support the rudder plate, piece **13**, are located at the pintle lugs; therefore, the lugs and arms are located by dimension to the centers. The center of the second pintle from the bottom is 4 feet $4\frac{13}{16}$ inches above the bottom of the rudder frame and the other pintle lugs and rudder arms are 4 feet $2\frac{1}{4}$ inches center to center. Obviously it makes no difference whether the dimension is from center to center or top to top if it is the same. As the pintle lugs and rudder gudgeons must all bear the same relation to one another, the above dimensions fulfil the case; for, subtracting $2\frac{9}{16}$ inches, which is half the depth of the lower pintle lug, from 4 feet $4\frac{13}{16}$ inches, gives the distance between the centers of the two lower pintle lugs to be 4 feet $2\frac{1}{4}$ inches, the same as elsewhere. From the Plan of Rudder Arms, it is seen that the pintle lugs have a radius of $3\frac{1}{2}$ inches at the forward end. This dimension also fixes the width transversely as twice the radius, or 7 inches.

Draw all the pintle lugs with their bottoms $\frac{3}{4}$ inch above the gudgeon and $5\frac{1}{8}$ inches deep. Show them in solid lines from the center line of the main piece to $3\frac{1}{2}$ inches forward of the center line of the pintles. Show small round corners drawn freehand at the forward ends.

43. As the twisting moment on the main piece of the frame decreases toward the bottom, the diameter is reduced from $7\frac{1}{4}$ inches at a point 9 inches below the coupling to $5\frac{1}{2}$ inches at the top of the lower pintle. Show this tapered main piece, using light pencil line for the after side, as it is to be a dotted line in places, and on the forward side omit it at the pintle lugs. A fillet is drawn freehand at the top and bottom of the lugs, the scale being too small to show the actual radius. Connect

the after side of the main piece with the under side of the coupling flange by an arc of 9-inch radius drawn in full. Draw the after edge of the rudder plate parallel to and 4 feet $7\frac{1}{2}$ inches aft of the center line of the main piece. With a 4-foot radius, draw an arc of a circle tangent to the after edge of the rudder plate and tangent to a horizontal line through the bottom of the main piece of the frame $18\frac{3}{4}$ inches above the base line. From the lower after corner of the coupling flange on the main piece of the frame, draw a light pencil line to meet the line of the after edge of the rudder plate continued at a point 3 feet 3 inches below the joint between the stock and the main piece. Draw an arc of a circle of 5-foot radius tangent to this line and to the after edge. These two arcs and the straight lines between and beyond each constitute the top, bottom, and after edge of the rudder plate.

44. The three center arms supporting the rudder plate are alike and extend from the main piece to 1 inch from the after edge of the rudder plate. These arms are $5\frac{1}{4}$ inches wide at the after end and $7\frac{1}{4}$ inches at the center line of the main piece. Draw these arms, noting that the middle arm is on the far side and hence in dotted lines and the other two are on the near side of the plate and hence in solid lines. In the Plan of Rudder Arms these arms are shown to be $4\frac{1}{8}$ inches thick at the main piece, and these lines are shown extending slightly forward of the center line of the main piece. The reason for this will be seen when drawing the detail of intermediate pintles on Plate 1061. The arms are connected to the main piece by a large fillet of 12-inch radius.

The upper side of the upper arm extends to a point 1 inch from the edge of the plate and 3 feet 3 inches from the center line of the main piece. Locate this point and draw a light pencil line through it parallel to the edge of the plate. Also draw a light pencil line through the top of the arm at the center line where the arm is $7\frac{1}{4}$ inches deep. With a radius of 2 feet, draw an arc of a circle tangent to these lines. The end of this arm is $5\frac{1}{4}$ inches deep and perpendicular to the edge of the plate, at its after end. Show the lower side of similar shape to

the top. The fillet connecting the arm to the main piece is of 12-inch radius for the lower side and of 3-inch radius for the upper, this latter dimension being shown on the Detail of Rudder Stock Coupling and Upper Pintle, Plate 1061.

The lower arm follows the contour of the plate to a point 3 feet 7 inches from the center line of the main piece. Its end is $5\frac{1}{4}$ inches deep, perpendicular to the plate edge, and its top side is similar to the bottom, widening out to the $7\frac{1}{4}$ inches depth of the main piece. There is a fillet of 12-inch radius at the top. Both the upper and the lower arms are on the far side and hence are dotted.

Between the rudder plate and the after side of the main piece, there is a space of $\frac{1}{16}$ inch. This space is too small to show on the arrangement drawing but it can be seen in the Detail of Rudder Stock Coupling and Upper Pintle on Plate 1061. The after side of the main piece is drawn in full lines except where the rudder arms are on the near side, in which places it is dotted.

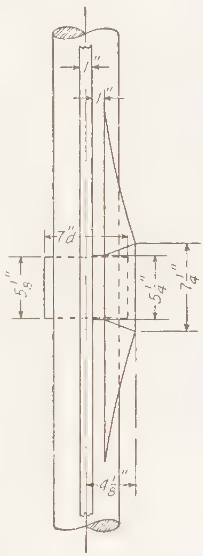


Fig. 7

45. Next draw the view of the Rudder Frame and Plate Looking Forward. This will be better understood by reference to Fig. 7, which is an enlarged end view of one arm. Draw the dash-and-dot center line of the end view of the rudder $3\frac{15}{16}$ inches from the left-hand border. Locate the joint of the coupling 20 feet 1 inch above the base line and draw the two circular flanges from given dimensions. Show the keeper, or retaining key, piece **19**, as dimensioned and drawn in the coupling detail on Plate 1061.

At a distance of $\frac{5}{16}$ inch, actual measurement, from the top border locate the top of the stock. The upper part is 2 feet $9\frac{1}{2}$ inches long and $7\frac{5}{8}$ inches in diameter. Connections to the steering gear are usually drawn after this drawing is developed; therefore, to allow for the development of this part it is shown large at this stage of the design and then

turned to the required size as would be shown on the later plans. Hence the note shown on the plate. The remainder of the stock is $7\frac{1}{4}$ inches in diameter. As there is not room to draw this full length and as this part is of constant diameter, it is shown broken. Cross-hatching for cast steel is to be drawn at the break. The 6-inch allowance marked on the length is for the same purpose as the enlarged diameter. Draw in full lines the edges of the plate $\frac{1}{2}$ inch each side of the center line. These lines will, of course, extend to the bottom of the rudder, which is $18\frac{3}{4}$ inches above the base line.

By light pencil lines, locate the top and sides of the lower pintle lug and the horizontal center lines, tops, bottoms, and sides of the other pintle lugs. The depth of the pintle lugs is $5\frac{1}{8}$ inches and the projected width 7 inches. Draw the projection of the main piece $7\frac{1}{4}$ inches in diameter at the top and $5\frac{1}{2}$ inches diameter at the lower pintle lug. This is a straight taper.

Alternating on the two sides of the rudder, represent the rudder arms by full vertical lines $4\frac{1}{8}$ inches off the center and $7\frac{1}{4}$ inches long, with the center of the length at the center of the pintle lugs. See Detail of Intermediate Pintles, Plate 1061. These lines represent the sides of the rudder arms at the main piece. One inch from the side of the rudder plate at the three middle lugs, and on the same side as the lines just drawn and centered the same, draw full lines $5\frac{1}{4}$ inches long. At the top and bottom of these lines draw full lines to the rudder plate. The rectangles thus formed represent the end views of the arms. For the top and bottom arms, these rectangles are projected from the side elevation. Connect the outboard corners with the ends of the $7\frac{1}{4}$-inch lines, thus completing the projection of the arms. For the three center arms these lines are straight, but for the upper and lower arms they will be slightly curved inward, as they are projections of lines curved in the side elevation but straight in the plan view.

The large 12-inch fillets where the arms join the stock are shown in this projection by lines extending from the ends of the $7\frac{1}{4}$-inch line to points 12 inches above and below the outer ends and 1 inch from the side of the plate. These fillets actually start before the width gets to $7\frac{1}{4}$ inches, but the difference

is too small to show here. No horizontal line is drawn at the ends of these curved lines because at that point the fillet is tangent to the stock. Draw full vertical lines 1 inch from the plate from the ends of these curved lines to the arm, to represent the edges of the fillets.

In inking this view make dotted all lines not actually seen from aft, which are the parts of the pintle lugs behind the stock or the arms, and the side lines of the stock behind the arms.

46. Next draw the view, Plan of Rudder Arms. At the same height as the center lines of the second and third pintle lugs from the top, draw dot-and-dash lines to represent the center lines of the ship. At a distance of $2\frac{5}{8}$ inches from the left-hand border, draw a vertical dot-and-dash line extending above and below the lines first drawn. The intersection of the three is the center line of the rudder stock. Aft of and parallel to this vertical line draw a similar one at a distance of $8\frac{1}{2}$ inches to a $\frac{3}{8}$-inch scale. The intersection of this line and those first drawn is the center line of the main piece of the rudder frame.

With these lines as centers, draw the Plan of Rudder Arms similar to the plan view shown in Detail of Intermediate Pintles on Plate 1061. Omit the pintle nuts, but describe two dotted circles, one 3 inches diameter and the other $3\frac{1}{2}$ inches diameter, to represent the holes for the pintles. Also, in this small-scale view the arm is shown complete, with no break in the plate and arm as in the detail.

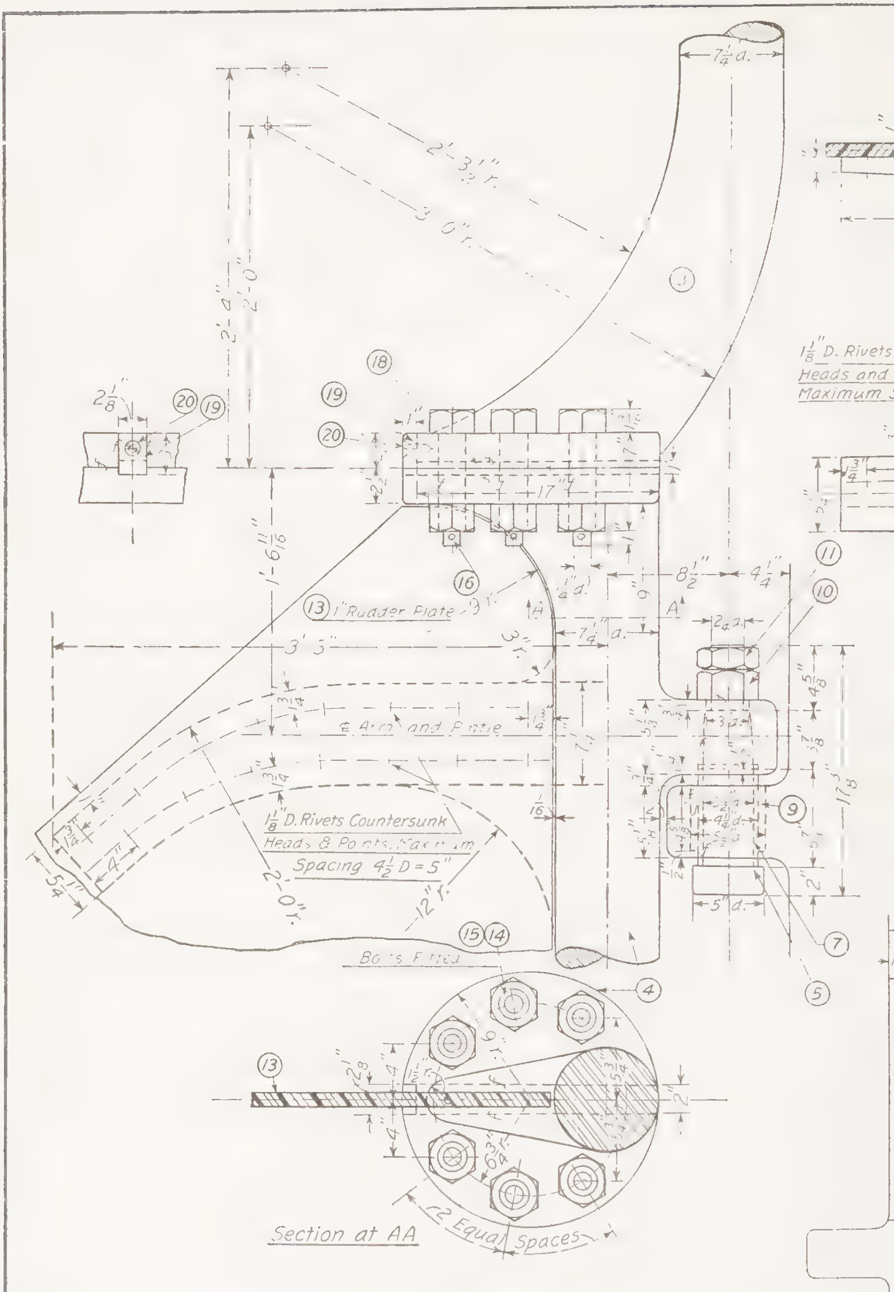
The drawing of the arms just referred to, the drawing of the lifting eyebolt, piece **17**, and of the riveting of the scarfs in the stern frame, should be deferred until after drawing these details on Plate 1061. The riveting on the shaft boss in the side elevation will be indicated as shown, the rows being located relatively to the plate edge, the same as in the scarfs. Being on a curved surface, the projection will not be the exact spacing.

PLATE 1061, TITLE: STERN FRAME AND RUDDER DETAILS

47. Plate 1061 consists of details of the stern frame and rudder shown on Plate 1060.

The first view to be drawn is Detail of Intermediate Pintles, and the scale to be used is $1\frac{1}{2}$ inches = 1 foot. A sectional plan and an elevation are to be shown. Draw the vertical center line of the main piece $5\frac{5}{8}$ inches, actual distance, from the right-hand border. Draw the center line of the pintles $8\frac{1}{2}$ inches, to scale, forward of the center line of the main piece. For the elevation, draw the horizontal center line of the rudder arm $4\frac{1}{4}$ inches, actual distance, below the top border, and for the section draw the center line of the blade, or center line of the ship, $1\frac{1}{4}$ inches below the border.

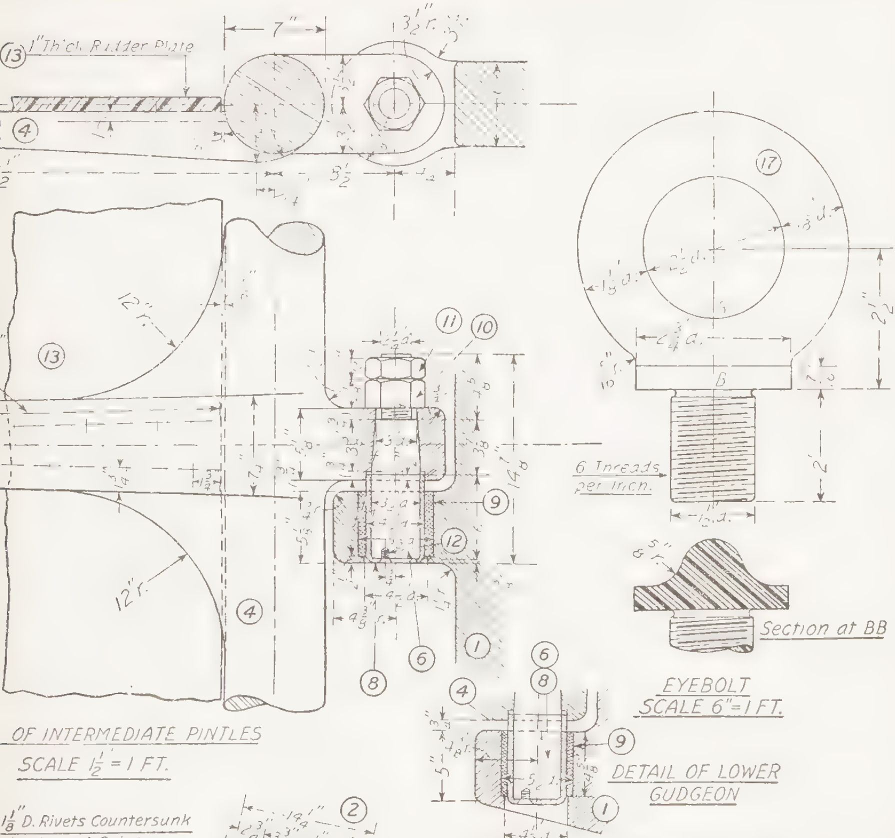
48. First draw the elevation. The diameter of the main piece, as has been shown on Plate 1060, varies from $7\frac{1}{4}$ inches at a point 9 inches below the coupling to $5\frac{1}{2}$ inches at the top of the lower pintle. Show the main piece 7 inches in diameter in this sketch and extending 15 inches above and 18 inches below the center of the arm. Show cast-steel cross-hatching where this is broken off. Draw the arm $7\frac{1}{4}$ inches deep at the center of the main piece and $5\frac{1}{4}$ inches deep at the end. The arm is broken, and the after end is shown 4 inches, actual distance, from the center line of the main piece. Draw the top and bottom lines converging according to the dimensions, but with allowance made for the break. Draw light center lines for rivets $1\frac{3}{4}$ inches from the top and bottom edges. Locate the rudder-plate edge $\frac{1}{16}$ inch, actual measurement, aft of the after side of the main piece of the frame. The aftermost rivet in the top row is $1\frac{3}{4}$ inches from the end of the arm and the forward rivet in the lower row is $1\frac{3}{4}$ inches aft of the plate edge. Other rivets are located as specified by the note on the drawing. Draw the fillets with 12-inch radius. Show the after side of the main piece and the forward edge of the plate dotted behind the rudder arm and full elsewhere. Draw in the rudder plate and show it broken at top, bottom, and back.



DETAIL OF RUDDER STOCK COUPLING
AND UPPER PINTLE
SCALE 1 1/2" = 1 FT.

DETAIL OF
RUDDER
SCALE

DATE



OF INTERMEDIATE PINTLES
SCALE $1\frac{1}{2}$" = 1 FT.

EYEBOLT
SCALE 6" = 1 FT.

DETAIL OF LOWER GUDGEON

DETAIL OF SCARF IN PROPELLER POST.
SCALE 1" = 1 FT.

FOR GEN. ARRANG. SEE PL. 1060

1	#34 Std F H Cs'k [illegible] Screw	20	Brass		
1	Retaining Key for Coupling	19	Medium Steel		
1	Tapered Key for Coupling	18	Medium Steel		
1	Eyebolt for Lifting Stock	17	Medium Steel		
6	$\frac{5}{16}$" Dia. Split Pin, 2" Long	16	Brass		
6	2" Standard Hex. Nut.	15	Medium Steel		
6	2" Dia. Hex. Head Bolts	14	Medium Steel		
1	Rudder Plate.	13	Ship Steel		
4	#24 Std Cs'k Head Mach Screw	12	Brass		
5	$2\frac{1}{4}$" Hexagonal Jam Nut	11	Medium Steel		
5	$2\frac{1}{4}$" Hexagonal Nut.	10	Medium Steel		
5	Bushings for Gudgeons	9	White Metal		
4	Bushings for Lower Pintles	8	Comp. H		
1	Bushing for Upper Pintle	7	Comp. H		
4	Lower Pintles	6	Medium Steel		
1	Upper Pintle	5	Medium Steel		
1	Rudder Frame	4	Cast Steel	Pattern	D
1	Rudder Stock	3	Cast Steel	Pattern	C
1	Stern Post Upper	2	Cast Steel	Pattern	B
1	Stern Post Lower	1	Cast Steel	Pattern	A

STERN FRAME AND RUDDER DETAILS

DRAWN BY________
DATE________

1061

Name, Class Letters, and Number

Locate the vertical center line of the pintle lug $8\frac{1}{2}$ inches forward of the center of the main piece. This lug extends $3\frac{1}{2}$ inches forward of the center of the pintle, as shown by the dimension $3\frac{1}{2}$-inch radius given on the plan. It is $5\frac{1}{8}$ inches deep and located on the same center line as the arm and is connected to the main piece by fillets of $1\frac{1}{2}$-inch radius; the upper and lower corners are rounded with a $\frac{3}{4}$-inch radius.

49. In the plan, draw the main piece 7 inches in diameter. As this is tapered and has the top and bottom diameters ($7\frac{1}{4}$ inches and $5\frac{1}{2}$ inches) given on the elevation in Plate 1060, no dimension would be given on a working drawing. This is a general detail and does not apply to any one arm. Draw the arm with the inner edge—that is, the edge next to the rudder plate—$\frac{1}{2}$ inch from, and parallel to, the center line and of a thickness of 1 inch at the outer end. At the inner end the outer edge of the arm is $4\frac{1}{8}$ inches off the center line, and the arm terminates in an arc of 5-inch radius tangent to the main piece. The arm is dimensioned 4 feet $6\frac{1}{2}$ inches long, 1 inch shorter than the width of the rudder plate as shown in Plate 1060, where the distance from the end of the arm to the edge of the plate is given as 1 inch. Show the end of the arm exactly above the end in the elevation. Show the break approximately above that in the elevation and draw the outer edge with the proper taper, making allowance for the part omitted at the break. Draw the rudder plate 1 inch thick, $\frac{1}{16}$ inch from the after edge of the main piece of the frame and extending 1 inch, to scale, aft of the arm. Cross-hatch the rudder plate for medium steel. Project up the center line of the top row of rivets from the elevation.

50. With the center line of the pintle as center, draw a semicircle of $3\frac{1}{2}$-inch radius for the forward end of the pintle lug and continue the sides parallel to the center line back to the main piece of the rudder frame. From the point of tangency of the arc of 5-inch radius with the main piece in the plan, project to the elevation points to locate the terminations of the lines forming the top and bottom edges of the arm. Continue the lines that represent the top and bottom of the

pintle lugs to the projection of that point in the plan where the near side of the lug meets the 5-inch-radius arc of the termination of the arm. In the plan, draw a line 1 inch from the plate and extending aft 12 inches from the main piece of the frame. This represents the upper edge of the fillet.

51. At a distance of $4\frac{1}{4}$ inches forward of the center of the pintle in the plan, draw the after edge of the rudder post 3 inches each side of the center line. Round the corners with a $\frac{1}{2}$-inch radius. With the center of the pintle as a center, draw the plan of the rudder gudgeon with a $4\frac{3}{8}$-inch radius. This outline encircles the after part of the gudgeon and merges into the rudder post with an arc of 3-inch radius. The gudgeon is shown dotted below the pintle lug. Cross-hatch the main piece of the rudder frame and the rudder post for cast steel.

In the elevation, draw the gudgeon and rudder post as dimensioned and projected from the plan. Note here that the gudgeon and pintle lug are $\frac{3}{4}$ inch apart as was indicated on Plate 1060.

52. In the pintle lug, draw the tapered hole for the pintle with a diameter of 3 inches at a depth of $\frac{3}{4}$ inch below the top, and $3\frac{1}{2}$ inches diameter at a point $\frac{1}{2}$ inch above the bottom. In the plan, the hole is shown by a dotted circle 3 inches in diameter. The bottom of the lug is counterbored $4\frac{1}{4}$ inches in diameter and $\frac{3}{4}$ inch deep to take piece **8**, the bushing on the pintle, which, however, projects only $\frac{1}{2}$ inch into the lug. The threaded part of the pintle, piece **6**, is $2\frac{1}{4}$ inches in diameter from the top to a point $\frac{3}{4}$ inch below the top of the lug and this part is $4\frac{5}{8}$ inches long. The part is shown in the plan by a circle $2\frac{1}{4}$ inches in diameter.

A full straight line across the pintle $\frac{3}{4}$ inch below the top of the lug indicates a shoulder on the pintle, at which point it is 3 inches in diameter, then it tapers for a distance of $3\frac{7}{8}$ inches below, where its diameter is $3\frac{1}{2}$ inches. This diameter extends for 6 inches to a point $\frac{3}{8}$ inch above the bottom of the gudgeon. Draw the pintle nut, piece **10**, and locknut, piece **11**, in plan and elevation of the proportions as illustrated in *Mechanical Drawing,* Fig. 32, and Table I, except as to depth, which in

this case is not standard and is given on the plate. The top and the bottom of the locknut are alike.

The shoulder on the pintle, $\frac{3}{4}$ inch below the top of the pintle lug, allows the pintle, which is finished throughout its taper and the lower parallel part, to be firmly drawn up into the pintle-lug hole by means of the nut **10**, and then nut **10** is locked in place by screwing nut **11** down hard on **10**. The top of the lug is finished (indicated by *f*) in order to get a perfect seating for the nut.

To allow the pintle to turn in the gudgeon and not be acted on by salt water, it is protected throughout its turning surface by a composition bushing, piece **8**, which extends $\frac{1}{2}$ inch into the pintle lug and is $\frac{3}{8}$ inch thick on the bottom, thus being flush with the bottom of the gudgeon. The bushing is $\frac{3}{8}$ inch thick on the sides, the outside diameter thus being $4\frac{1}{4}$ inches, and it is held on the pintle by the brass machine screw, piece **12**, which is located on the center line of the ship and $\frac{3}{4}$ inch aft of the center line of the pintle. The screw is 1 inch long.

The hole in the gudgeon is finished and is $5\frac{1}{2}$ inches in diameter down to $\frac{1}{2}$ inch from the bottom of the gudgeon, below which point the hole is $4\frac{1}{2}$ inches in diameter. Fitting in this larger hole and surrounding the pintle bushing, is a white-metal bushing, piece **9**, for the gudgeon. This bushing cannot slip out on account of the shoulder in the gudgeon $\frac{1}{2}$ inch above the bottom, on which the bushing rests. The side surfaces of both bushings are finished. By putting tallow above the shoulder in the pintle and below the shoulder in the pintle lug, the pintle is completely protected from the action of salt water. Cross-hatch the various parts as shown.

53. The Detail of Lower Gudgeon is drawn with the center line of the pintle $3\frac{3}{8}$ inches from the right border and the top of the gudgeon $6\frac{3}{4}$ inches from the top border. The parts of the pintle lug and pintle and the bushings are the same as in the detail just drawn. The total height of the gudgeon bushing is marked $4\frac{5}{8}$ inches, which is the same as that already drawn where the height equals the depth of the gudgeon less the shoulder, or $5\frac{1}{8}$ inches $-\frac{1}{2}$ inch $= 4\frac{5}{8}$ inches. The gudgeon

is 5 inches deep, and from the lower corner it slopes forwards to the base line as shown in the side elevation, Plate 1060. In the detail to be drawn, lay off the sloping line from the lower after corner of the gudgeon, making the angle equal to the angle of the bottom of the shoe shown in the Side Elevation of the arrangement drawing, in Plate 1060. This angle may be constructed by the method given in Problem 7, *Geometrical Drawing,* Part 2. The lower after edge of the gudgeon will have a radius of $\frac{3}{4}$ inch the same as the upper. The only difference of this from the detail of the intermediate pintles is the slope and the length of the bottom hole.

54. Next draw the Detail of Rudder Stock Coupling and Upper Pintle, also to a scale of $1\frac{1}{2}$ inches = 1 foot. The vertical center line of the stock is $6\frac{3}{8}$ inches from the left-hand border. Locate the joint between the coupling flanges of pieces **3** and **4**, 4 inches below the top border. Draw the center line of the main piece of the rudder frame $8\frac{1}{2}$ inches, to scale, aft of the center line of the stock. Similarly to the side elevation on Plate 1060, draw the outline of the stock and coupling. The sloping line of the rudder plate may be determined by pencil construction lines laid out as described for Plate 1060, but extending only far enough to show the top rudder arm. Draw the main piece of the rudder frame extending below the joint with piece **3** and including the pintle lug and the top arm, the center line of the latter being 1 foot $6\frac{1}{16}$ inches below the joint, in the manner previously described. The outline of the rudder gudgeon and part of the after edge of the rudder post extending above and below the gudgeon are next drawn, the gudgeon being the same as drawn in the Detail of Intermediate Pintles. The forward edge of the rudder plate is drawn $\frac{1}{16}$ inch aft of the rudder frame. Draw the center line of the rivets $1\frac{3}{4}$ inches, to scale, from the top and bottom edges of the arm and locate the end rivets in each row from dimension given. There are eight rivets in the top row and seven in the bottom row spaced equally.

55. Next draw section *A A,* which is taken on a line 8 inches below the bottom of the coupling flange. The arrows

pointing upwards indicate that the view is from below. The center line of this section is $3\frac{3}{8}$ inches, actual distance, above the lower border. The main piece of the rudder frame is drawn with a diameter of $7\frac{1}{4}$ inches. The coupling with its forward edge coincident with the forward edge of the main piece is next drawn, and then the 1-inch plate is shown broken off. The point of tangency of the 9-inch-radius arc connecting the main piece and the bottom of the coupling flange is projected down from the elevation onto the plan, and an arc of $1\frac{1}{2}$-inch radius with its center on the center line is drawn through the point thus projected. Straight lines, drawn tangent to the sides of the main piece and to this arc, complete the contour of the intersection of the main piece and the coupling flange.

56. Draw the pitch circle of the 2-inch-diameter coupling bolts with a $6\frac{3}{4}$-inch radius and locate the end bolts on each side 4 inches and $5\frac{3}{4}$ inches, respectively, off the center line. The intermediate bolts are half way between on the pitch circle. At the centers of the bolts, draw circles 2 inches and $1\frac{1}{4}$ inches in diameter, the first being the diameter of the bolt and the second the reduced diameter of the bolt below the nut. Draw this view of the nuts as shown and dimensioned in Fig. 32 and Table I in *Mechanical Drawing.* Project the center lines of the bolts to the elevation and draw the shanks of the bolts 2 inches in diameter for a distance 7 inches below the top of the upper flange. Beyond this point, for a distance of 1 inch the diameter of the bolt is reduced to $1\frac{1}{4}$ inches, a shoulder being thus formed flush with the outer face of the nut. In the elevation draw the bolt heads and nuts according to the above references. Indicate holes, here shown $\frac{1}{2}$ inch in diameter, for the split pins, piece **16.** These bolts are body-bound, or fitted, and hence marked *f*.

57. The coupling is further secured against horizontal movement by a tapered key on the fore-and-aft center line of the rudder. The key, which in the plan view is shown by two dotted lines, is 2 inches wide at the forward end and $2\frac{1}{8}$ inches at the after end, and fits in slots $\frac{1}{2}$ inch deep in both

the flange on piece **3** and on piece **4.** This key is secured in place by a straight vertical key, $2\frac{1}{8}$ inches wide, fitted in a groove 1 inch deep in the after part of the stock, piece **3.** The three grooves are exactly in line at the after end. The horizontal key, which is 17 inches long and extends, when in place, from the front of the coupling to the bottom of the vertical groove, is driven in first. Then the retaining key is put on and covers the after end of the first and is flush with the surface of the coupling. This retaining key is held in place by a No. 34 standard flat-head countersunk machine screw, 2 inches long.

The head is drawn 1 inch in diameter and the shank $\frac{5}{8}$ inch in diameter. The center of the screw is 1 inch below the top of the flange on the stock.

In the plan, the vertical key is shown by a straight dotted line 1 inch from the after side at the center of the horizontal keyway. Draw the bottoms of the horizontal grooves in the elevation $\frac{1}{2}$ inch above and below the joint and the upper one extending to 1 inch from the after side at the center line. A vertical dotted line shows the vertical key which covers the end of the horizontal key, and the vertical key is secured by the brass machine screw. All surfaces of both keys are machined. Draw the end view, which is self-explanatory, with the center line $1\frac{1}{8}$ inches from the right-hand border.

58. In the elevation, the holes in the gudgeon and in the pintle-lug bushing, piece **9,** and the nuts, pieces **10** and **11,** are the same as described in Detail of Intermediate Pintles. This pintle has a head which prevents the rudder jumping out of the bearings in a seaway. The straight part of the pintle, $3\frac{1}{2}$ inches in diameter, extends for $6\frac{7}{8}$ inches, instead of 6 inches as in the other view. Below this is a flat head, 5 inches in diameter and 2 inches deep. The composition bushing, piece **7,** extends to the under side of the head, the lower corners of which are slightly rounded off freehand. The pintle and bushings are here shown in dotted lines, while the gudgeon and pintle lugs are not broken away or cross-hatched as they were in the other detail.

59. Next draw the details of the scarf riveting to a scale of 1 inch=1 foot. First draw the scarf in the rudder post with the after side of the post $7\frac{3}{4}$ inches from the left-hand border. Locate the top of the scarf $4\frac{1}{2}$ inches above the lower border. Next locate the top of the gudgeon below the top of the scarf. From the side elevation in Plate 1060, the top of the scarf is 16 feet 3 inches above the base line. From the view of Rudder Post Looking Forward, on the same plate, the top of the gudgeon is found to be $16' 3'' - (18'' + 3 \times 4' 2\frac{1}{4}'') = 2$ feet $2\frac{1}{4}$ inches below the top of the scarf. Draw the gudgeon as per dimensions previously described. Draw the outline of the scarf and stern frame from dimensions here given. Locate the rivet lines and tick the rivet centers as required.

60. The scarf in the propeller post is to be drawn at the proper slant. In this case mark a point on the lower border line 6 inches from the right-hand border. Then, $4\frac{7}{8}$ inches from the right-hand border and 5 inches above the base line mark another point. Through these points draw a line which will be the forward side of the propeller post. Draw a line $14\frac{1}{4}$ inches (to 1-inch scale) aft of and parallel to the first line. This is the after side of the propeller post. Locate the top forward corner of the scarf $4\frac{1}{2}$ inches, actual measurement, above the border and along the line of the forward side. The scarf is 2 feet $4\frac{1}{2}$ inches long, therefore from the top and bottom ends draw lines perpendicular to the sides of the post, the top dotted and bottom full. Continue the sides below the scarf and the after side above the scarf. The edge of the shell plate is 1 inch from the after edge of the post and is indicated by a dash line. Rivet lines and rivets will be located where shown. Only the two after rows of rivets are continued above and below the scarf, the spacing clear of the scarf being $5\frac{5}{8}$ inches.

61. Next draw the Eyebolt. To lift the rudder from the gudgeons for removing it or for overhaul of the pintles or the deck bearing, an eyebolt is provided in the top of the rudder stock. Incidentally it may be noted that the weight of the rudder is not carried by the pintles, but by a bearing on the deck, so that the only work which the pintles perform is to

resist side pressure and serve as bearings on which the rudder turns. The eyebolt is to be drawn to a scale of 6 inches =1 foot.

Draw the vertical center line of the eyebolt $1\frac{13}{16}$ inches, actual distance, from the right-hand border. At a distance of $3\frac{3}{4}$ inches below the top border, locate the shoulder or base of the eye, which is drawn $2\frac{3}{4}$ inches in diameter and $\frac{7}{16}$ inch thick, to scale. Locate the center of the eye $2\frac{1}{2}$ inches above the shoulder and draw the inside of the eye $2\frac{1}{2}$ inches in diameter and the outside $4\frac{3}{4}$ inches in diameter. The latter is not a complete circle but is connected to the top of the base by arcs of radii of $\frac{5}{16}$ inch that are tangent to the sides of the base. The shank is $1\frac{1}{2}$ inches in diameter and 2 inches long below the shoulder. A groove is shown cut immediately under the shoulder to allow the screw-eye to be bolted up snug to the rudder stock. The threads are drawn and shown in the manner explained in *Mechanical Drawing,* Plate 1003.

62. Below the elevation, draw Section at *BB,* locating the shoulder $5\frac{11}{16}$ inches below the top border. Make the height above the shoulder at the center equal to that in the upper elevation. With a center on the center line of the section and a radius of $\frac{9}{16}$ inch, same as the wire radius of the eye, draw an arc. On each side connect this arc to the flat top of the shoulder by arcs of $\frac{5}{8}$-inch radius. Show a portion of the screw as before. Cross-hatch the lower section. This plate is then to be finished by putting on all the lettering and dimensions, also the material list and the title and number of the plate.

63. When these details are completed, the parts that were left incomplete on Plate 1060 should be finished according to the instructions given in connection with the drawing of the details. Then both the plates are to be completed by putting on all the lettering and their respective titles and numbers, the schedule of parts, or material list, for the two plates being put on Plate 1061 as shown.

PLATE 1062, TITLE: AIR PORT

64. Ships, like buildings, require windows for the admission of light and air. But, through the sides of a vessel and through the sides of some deck houses, the windows in a ship are circular instead of rectangular. In some deck houses, more particularly in large passenger steamers, special rectangular windows are provided. In steel structures, these windows are practically always set in cast-metal frames.

Circular windows, often called lights, if made to open are called *air ports;* those that do not open and are for the admission of light only are called *fixed lights;* the circular frame holding the glass is called the *light-frame,* and the glass itself is often spoken of as a *light.*

A cover, either hinged or portable, which can be put over the inside of the air port is called a *dead cover* or *dead-light.*

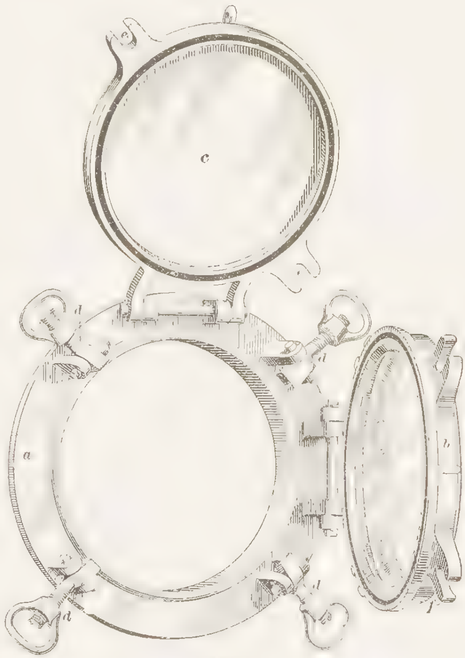


FIG. 8

Such a cover when closed keeps the inside illumination from shining outside and also keeps the compartment dry if the glass becomes broken. Water-tightness is obtained by having the window or deadlight close against a rubber gasket to which it is held fast by dogs or hinged bolts and ring nuts.

Fig. 8 shows an air port and dead cover. In this view, *a* is the port-frame, *b* the light frame, *c* the dead cover, *d* the dogs for holding them shut, and *e* and *f* are lugs by which either the

dead cover or the light-frame, or both, can be fastened open when desired.

65. On Plate 1062 are shown an elevation of and a cross-section through an 11-inch air port and its dead cover. The air port consists of a malleable cast-iron frame, piece **1**, called the *port-frame,* which is fastened to the shell by twelve $\frac{1}{2}$-inch tap bolts, piece **14.** Piece **2,** though not shown, is the same as piece **1,** except that it is left-handed; that is, it has the hinge on the other side, being so made for use on the opposite side of the ship. There are lugs on the right-hand side of this frame, piece **1,** and hinging in these on the pin, piece **3,** is the composition light-frame, piece **4,** which contains the glass, piece **5.** The glass is held in piece **4** by the retaining ring, piece **6,** which is threaded and screws up inside of piece **4.** The glass is sealed in the light-frame, piece **4,** by white-lead putty. A groove in the outer side of piece **4** contains a rubber gasket, piece **7,** which is compressed against the port-frame, piece **1,** when the four ring nuts, piece **8,** on the dogs, pieces **9** and **15,** are screwed down against the lugs cast on the light-frame, piece **4.**

The dogs are hinged on pins, piece **10.** These dogs, or tumble bolts, swing up into the lugs cast on piece **4,** which lugs are hollowed out in a straight taper that fits the tapered bottom of the ring nuts. A shoulder is cast on the foot of the dog, as shown on the partial detached view at the left side of the plate. This shoulder keeps the dog perpendicular to the frame and thus facilitates the proper seating of the nut in the hollowed-out lug. The dog can turn on its hinge away from the port-frame and lie against the shell.

The cast-iron dead cover, piece **11,** is hinged at the top on the pin, piece **3,** which is held in lugs cast on piece **1.** Hinge pins, piece **3,** are held in place by $\frac{1}{8}$-inch split pins, piece **12,** in each end. The dead cover has a groove containing a rubber gasket, piece **13,** similar to the groove and gasket in the light-frame. This gasket is held tight against the round-pointed edge of the retaining ring, piece **6,** when the two ring nuts, piece **8,** on the dogs, piece **15,** are screwed down tight on the

two lugs cast on the dead cover. The dogs, piece **15,** hinge on pins, piece **10,** in lugs cast on the port-frame, piece **1.** Pins, piece **10,** are held in place by split pins, piece **12,** in the ends. Nuts, piece **8,** are kept from being screwed off the dogs, pieces **9** and **15,** by split pins in the upper end of the dogs. The lugs on the dead cover are similar to those on the light-frame. A lug is cast on the bottom of the dead cover, as shown on the elevation and in a detached view, by which a hook on a chain (not shown) can hold the dead cover when swung up on its hinge so as to be clear of the port; then the nuts which hold the dead cover tight may be screwed down farther on the dogs, piece **15,** so as to be in contact with the lugs cast on the light-frame, piece **4.**

As will be seen in the elevation, the dead cover has only two lugs and these are held by the dogs, piece **15;** these lugs are shown in the upper right and the lower left quadrants. There are, however, four lugs on the light-frame, two of which are immediately under those on the dead cover and therefore held by the same dogs, piece **15,** and the other two, shown in the upper left and the lower right quadrants, are held by the shorter dogs, piece **9.** In the upper quadrants, the ring nuts, piece **8,** are shown in place on the dogs, pieces **9** and **15;** in the lower quadrants the nuts and dogs are not shown.

A lug in the elevation is shown at the left of the light-frame for holding it open when swung about its hinge at the right.

The nominal size of the port, 11 inches, is the inside diameter of the port-frame, piece **1.**

66. In describing the drawing of this port, direction *away from the center of the ship,* toward the outside of the shell, will be designated as **outboard** and the opposite direction as **inboard.** Direction *away from the center of the port,* toward its circumference, will be referred to as **outside** and the opposite direction as **inside.** Thus, in the section, toward the bottom is *outboard* and toward the top is *inboard.* In the elevation, the terms inside and outside have their usual meanings and they are applied in exactly the same manner in the section.

The scale of this drawing is to be $\frac{3}{4}$ full size, or $\frac{3}{4}$ inch = 1 inch. The draftsman's ordinary $\frac{3}{4}$ scale is graduated to 24ths, therefore dimensions as small as $\frac{1}{8}$ inch can be read direct in 24ths, and smaller ones can be estimated.

67. To draw the plate, first draw a light pencil line $2\frac{5}{8}$ inches, actual distance, above the lower border and extending across the plate. This line represents the outboard side of the shell plate. Indicate its inboard side by another pencil line $\frac{11}{16}$ inch, to scale, above the first. Since the shell plate is only incidental, it is not dimensioned on the drawing, the details of the air port being the main feature. The opening in the plate is shown on the right-hand side by a straight line perpendicular to and between the other lines and $1\frac{3}{4}$ inches, actual distance, from the right-hand border. As the sides of the light-frame are $\frac{5}{16}$ inch thick, the opening in the plate will be $11''+2\times\frac{5}{16}''=11\frac{5}{8}$ inches in diameter. Locate the left-hand side of this opening, and on each side, $\frac{5}{16}$ inch inside of the plate opening, draw light vertical pencil lines to indicate the sides of the clear opening of 11 inches in the air port. Locate the center of the opening and draw a dot-and-dash center line perpendicular to the shell plate and extending to the top border. On this, 11 inches, actual distance, above the lower border will be the center for the elevation, on which, to scale, draw a dotted circle 11 inches in diameter representing the clear opening. This is dotted because it will be behind the dead cover, and the light-frame.

The port-frame flange, piece **1**, is $1\frac{15}{16}$ inches wide and is $\frac{7}{16}$ inch thick except where the lip projects out through the shell plate and upwards to make contact with the rubber gasket, piece **7**. In the plan, locate the outside of the frame, piece **1**, $1\frac{15}{16}$ inches beyond the inside of the clear opening and draw the frame $\frac{7}{16}$ inch thick over the shell plate. The corner has a $\frac{1}{8}$-inch radius. In the elevation, draw a full circle $11''+2\times1\frac{15}{16}''=14\frac{7}{8}$ inches in diameter which will be the outside of the frame. The part of the frame projecting through the shell plate is $\frac{7}{8}$ inch deep from the inside of the shell and terminates in a semicircle $\frac{5}{16}$ inch in diameter. The center line of the

inner lip and also the center line of the rubber in the light-frame, piece **4**, is on a circle $11\frac{1}{4}$ inches in diameter. The top of the lip is $\frac{5}{16}$ inch above the top of the flange of the light-frame and the tip is an arc of $\frac{1}{16}$-inch radius. The sides are arcs of $\frac{3}{8}$-inch radii, the inner arc being tangent to the straight inside of the frame, and the tip arc and the outer arc being tangent to the tip arc and an arc of $\frac{1}{8}$-inch radius that is tangent to the top surface of the flange. The order of drawing these arcs is that in which they are first mentioned.

68. The light-frame, piece **4**, sets up against the tip of the port-frame. This light-frame is $1\frac{5}{16}$ inches deep, the outside diameter of the outboard part is 12 inches, and the outside diameter of the inboard part is $11\frac{3}{8}$ inches. The outboard shoulder is $\frac{3}{8}$ inch deep and is connected to the inner and outer sides by small arcs drawn freehand. The inside clear diameter of the light opening is 10 inches. The outboard side of the frame is beveled; the diameter at the outside of the bevel is $10\frac{5}{8}$ inches. The bevel is $\frac{5}{32}$ inch deep and the thickness of the inner edge of the frame inboard of the bevel is $\frac{1}{8}$ inch. To make it tight, the glass is set in white-lead putty. In the drawing, the glass, which is $10\frac{1}{2}$ inches in diameter and $\frac{3}{4}$ inch thick, is shown setting away from the light-frame a distance of $\frac{1}{64}$ inch and a like distance is indicated between the glass and the retaining ring, piece **6**.

When drawing a structure made up of parts that are to be assembled one on another, as in this case, it is always advisable to sum up the dimensions of the individual parts and check them with the over-all dimension of the part. In this case, dimensions given on the drawing show that the retaining ring screws into the light-frame a distance of $\frac{1}{4}$ inch and the given dimensions of the parts of the light-frame that are outboard of the glass are $\frac{1}{8}$ inch and $\frac{5}{32}$ inch. The over-all depth of the light-frame is $1\frac{5}{16}$ inches. Then the space left for the glass is $1\frac{5}{16}-(\frac{1}{4}''+\frac{1}{8}''+\frac{5}{32}'')=\frac{25}{32}$ inch. As the glass is $\frac{3}{4}$, or $\frac{24}{32}$, inch thick, the clearance is $\frac{25}{32}''-\frac{24}{32}''=\frac{1}{32}$ inch, which, divided equally each side of the glass, gives the required $\frac{1}{64}$ inch clearance between the glass and the metal.

The dimensions of the groove for the rubber in this light-frame are shown in the sectional detail at the upper left-hand corner of the plate. The inside diameter of the light-frame at the outer face of the glass is $10\frac{9}{16}$ inches. This diameter continues for $\frac{1}{4}$ inch, and then for a distance of $\frac{1}{8}$ inch it tapers to the larger $10\frac{7}{8}$ inches diameter. In the elevation, draw light pencil circles 12 inches and $11\frac{3}{8}$ inches in diameter representing the outside of the light-frame.

69. The outside and inside diameters of the retaining ring are 11 inches and 10 inches, respectively. The threads on this ring are twelve per inch. The diameter of the tip of this ring and likewise the diameter of the center line of the rubber gasket, piece **13,** which closes water-tight on this tip, is $10\frac{1}{2}$ inches. The depth of the ring is $\frac{7}{16}$ inch and in its normal position the outer surface is $\frac{1}{4}$ inch within the light-frame. Show the tip with an arc of a radius of $\frac{1}{16}$ inch and draw the remainder of the sections of the ring by the diagonal lines tangent to this arc, one extending to the outer thread at the level of inside of the light-ring and the other to a point 5 inches (half the inside diameter) from the center line and $\frac{3}{16}$ inch from the outboard surface of the ring. Then draw vertical lines $\frac{3}{16}$ inch deep defining the inside diameter, and draw a horizontal line representing the face next the glass, this face being $\frac{1}{4}$ inch inside the light-frame. The line representing this face and the line of the tip, or knuckle, of the ring are continued all the way across, as are similar lines of the light-frame and the glass, because these will be seen when looking toward the half section. No lines representing any part of this retaining ring appear on the elevation, as this ring is entirely behind the dead cover, piece **11.**

70. Next, the dead cover is drawn with the surface of the rubber in the groove just tangent to the tip of piece **6.** The groove in piece **11** is the same as that in piece **4,** as is shown by the dimensions in the detail just below the center of the elevation.

The outside diameter of the dead cover is $11\frac{1}{4}$ inches and the depth through which this diameter holds constant is $\frac{3}{8}$ inch.

At a distance of $\frac{3}{16}$ inch from the outboard face of the cover is the outer surface of the flat main part of the cover, and this part is $\frac{3}{16}$ inch thick. The thicker shoulder that extends outboard of the flat part all around the edge has an inside diameter of $9\frac{7}{8}$ inches.

On the inboard side, the cover is stiffened around the edge by a ridge, or circumferential web, that has a diameter of $10\frac{1}{2}$ inches at the center line of the ridge. This is also the diameter of the center line of the rubber groove in piece **11** and also the center line of the tip of piece **6.** The total thickness of the dead cover through the ridge is $\frac{3}{4}$ inch. The top of the ridge is formed by an arc of $\frac{1}{8}$-inch radius. The profile of the section at the edges is formed by drawing an arc of $\frac{1}{4}$-inch radius tangent to the top arc and passing through the outer edge of the cover $\frac{3}{8}$ inch from the outboard side, and by another arc tangent to the top arc and to the back of the cover. Draw the outer edge of the dead cover in the elevation $11\frac{1}{4}$ inches in diameter. Show the circumferential ridge, or web, by two circles, $10\frac{1}{4}$ inches and $10\frac{5}{8}$ inches in diameter, both to be drawn in light pencil line and not dimensioned. The dead cover is stiffened by four radial ridges, or webs, on the inboard side, which extend out at angles of 45 degrees each side of the vertical center line. These webs are $\frac{3}{16}$ inch thick and the sides are connected to each other at the center and to the circumferential web at the side by arcs of $\frac{3}{16}$-inch radius.

In the sectional view, a web is indicated as extending right across the cover, although in the elevation the webs are at 45 degrees with the center line. This is a conventional way to make clear the true cross-section and to define the extent of the web. The distance from the top, or inboard, edge of the web to the line of the outboard face of the dead cover is 1 inch at its center and at a distance of $2\frac{5}{8}$ inches from the center it is $\frac{15}{16}$ inch. The contour of the top of the web is drawn with a ship curve through these points and the top of the circumferential web. On the center line, a section of the transverse web is drawn $\frac{3}{16}$ inch thick and having a semicircular top tangent to the sides of the web. The sides of the web are shown connected to the dead cover by arcs of $\frac{1}{8}$-inch radii.

The port-frame, light-frame, retaining ring, dead cover, and gaskets are cross-hatched to indicate the proper materials as shown on the schedule of parts.

71. The hinges on which the light-frame and the dead cover swing are $6\frac{5}{8}$ inches from the center, those of the light-frame being on the right-hand side and those of the dead cover at the top. In the elevation, both hinges are shown in their proper places, but in the cross-section the position of the hinge of the dead cover is shown conventionally, it being swung around to the right-hand side of the view to the same plane as the hinge of the light-frame. This is done because, since the hinges of the light-frame and the dead cover are alike in many of their parts, it is thereby possible to save the making of another view. The parts wherein the dead-cover hinge differs from the other are shown dotted.

In the section, the hinge lug is drawn by first locating a point $6\frac{5}{8}$ inches to the right of the center line and $1\frac{1}{16}$ inches inboard of the inner surface of the port-frame, piece **1**. With this point as a center, draw an arc of $\frac{1}{2}$-inch radius, also two lines tangent to this arc and perpendicular to the port-frame, and connecting to the frame by arcs of $\frac{1}{8}$-inch radius. Show an oval hole extending $\frac{17}{64}$ inch inboard of and $\frac{3}{8}$ inch outboard of this point and $\frac{17}{32}$ inch wide. The $\frac{1}{2}$-inch-diameter hinge pin, piece **3**, is thus given $\frac{1}{32}$ inch lateral clearance and $\frac{1}{8}$ inch allowance in the lugs when the light-frame and dead cover are compressed against the rubber gaskets. In the elevation, draw these lugs $1\frac{3}{8}$ inches each side of the axis of the air port and $\frac{5}{8}$ inch wide. The curved lines extending from three corners indicate the fillets where the lugs join the frame. At the fourth corner the lug slightly overhangs the frame and there would of course be no fillet.

72. In the section, the side view of the lugs on the light-frame and dead cover is shown with the center of the hole for the hinge pins at the point first located for drawing the lugs on the port-frame. To facilitate making the light-frame and dead cover, this center is dimensioned from some point in each

piece; in this case, $\frac{3}{4}$ inch from the outboard side of each. Draw the pin $\frac{1}{2}$ inch in diameter, and with its center at the point just located. The pin will be the same for both hinges. As the section is through the horizontal axis of the port, the upper hinge lug will be shown and it will be dotted where it is behind the lug on the port-frame.

The outside ends of the hinge lugs are represented by a semicircle of $\frac{1}{2}$-inch radius drawn to the right of the vertical center line of the pin, having the same center as the pin and in part coinciding with the curved edge of the port-frame lug. The lower part of this semicircle, between the side of the port-frame lug and the center line, is shown dotted.

The outboard side of the lug on the light-frame is represented by a horizontal line tangent to the outboard part of the semicircle representing the end of the hinge lug. This line is dotted where it is behind the lug on the port-frame and is connected to the light-frame by a small arc drawn freehand.

The inboard side of the lug is drawn by continuing a light line from the inboard face of the light-frame. This line is connected to the semicircular end of the hinge lug by an arc of $\frac{9}{16}$-inch radius that is tangent to both. The length of radius to use for this connecting arc is found as follows: The total depth of the light-frame is $1\frac{5}{16}$ inches and the center of the pin is $\frac{3}{4}$ inch from the outboard side, therefore the inboard side of the light-frame is $1\frac{5}{16}'' - \frac{3}{4}'' = \frac{9}{16}$ inch from the center of the pin, therefore this is the length of radius to use and the center will be on the horizontal center line of the pin and to the left of the vertical center line.

73. In the elevation of the air port, show the lugs on the light-frame $\frac{5}{8}$ inch thick where in contact with the port-frame lugs. The part of the lug from the contacting parts to the frame itself is $\frac{9}{16}$ inch wide, the side of the lug toward the end of the hinge pin being flush. These lugs connect to the outside diameters, 12 inches and $11\frac{3}{8}$ inches, of the light-frame by small fillets, drawn freehand.

In the elevation, draw the hinge pin, piece **3**, $\frac{1}{2}$ inch in diameter and extending $\frac{1}{4}$ inch above and below each light-

frame lug. These pins are retained in place by two $\frac{1}{8}$-inch split pins, piece **12**, in holes whose centers are $\frac{5}{32}$ inch from the ends of the hinge pin.

74. As previously explained, the hinge lugs and the pin for the dead cover are combined in the one sectional view in order to avoid making another drawing. The hinge pin and the lugs on the port-frame are the same as those for the light-frame hinge, and hence are not redrawn in the section. The hinge lug for the dead cover is shown dotted in the section and is drawn as follows:

With the pin center as a center, from the point where the dotted arc that represents the rounded end of the light-frame hinge intersects the vertical center line of the pin, continue the dotted arc to the horizontal center line to represent the rounded end of the dead-cover hinge. Then, tangent to this arc at its inner end, draw a short vertical line and connect this to the outer edge of the outboard face of the dead cover by a dotted arc of $\frac{1}{2}$-inch radius tangent to both.

75. To show the inboard edge of the hinge, draw an arc of a circle of $2\frac{1}{2}$-inch radius tangent to the top of the circumferential stiffener web and to the outside of the arc representing rounded top of the port-frame lug. This dotted arc is continued to the top surface of the dead cover as shown.

76. In the elevation, the hinge pin and the split pins in the ends are the same for the dead cover as previously drawn for the light-frame. In the elevation, the lugs on the dead cover are shown connected to circles representing the circumferential stiffener web by arcs of $\frac{3}{16}$-inch radii. These lugs on the dead cover extend inside the circumferential stiffener web and intersect the top surface of the dead cover at a point which is obtained from the sectional view, in which view the lug is shown to intersect the top surface of the dead cover by means of the dotted arc of $2\frac{1}{2}$-inch radius. In the elevation the lines representing these lugs terminate in small arcs drawn freehand, which indicate fillets at the bottom of the taper webs where they connect to the dead cover. The contour of the circum-

ferential ridge may now be drawn in ink as the arcs at the diagonal webs and at the hinge lugs have been located.

77. Located 45 degrees from the vertical and horizontal axes, and in line with the diagonal stiffening webs on the dead cover, are lugs on the light-frame that form seats for the dogs that hold it tight against the port-frame. The contour of these lugs is as shown in the lower right lug in the elevation. Locate the extreme end of the lug $7\frac{3}{16}$ inches from the center of the cover and draw the inside and outside side lines of the lug parallel to the 45-degree center line and spaced according to the given dimensions.

Draw arcs of $\frac{1}{8}$-inch and $\frac{3}{8}$-inch radii tangent to the inside and outside lines of the lug. Connect the outside straight lines of the lug to the $11\frac{3}{8}$-inch-diameter circle, which is the smaller circumference of the light-frame, by arcs of $\frac{15}{16}$-inch radii. The opening in the lug is $\frac{11}{16}$ inch wide and the sides are connected by an arc of $\frac{11}{32}$-inch radius described from a center on the bolt circle, which is of $6\frac{5}{8}$-inch radius. This is also the location of the center of the dog. The arc whose radius is $\frac{9}{16}$ inch indicates the top of the lug and the top edge of a conical surface of which the sides form a bearing for the dog. The other light-frame lugs are similarly drawn. At the upper right and the lower left are also lugs on the dead cover whose contours are identical with those on the light-frame, except that the straight lines forming the parallel sides $1\frac{5}{8}$ inches apart are slightly longer on account of the dead cover being of slightly smaller diameter than the light-frame. These sides are connected to the edge of the dead cover by arcs of $\frac{15}{16}$-inch radius.

The elevation of one of these lugs is drawn at the extreme left in the section. This arrangement is conventional, as the lug there shown is not a projection of any lug directly above. At the same place on the section, draw the elevation of the dog and the ring nut that secure both the dead cover and the light-frame.

78. Locate in the section the center line of the dog $6\frac{5}{8}$ inches from the center line of the port. Half an inch inboard

of the inner face of the port-frame locate the center of the dog pin, piece **10**, on the center line of the dog. Draw the end view of the pin, which will be a circle $\frac{3}{8}$ inch in diameter. (This dimension is given on the lower left of the elevation.) Draw the view of the lug in which the dog pin turns to the dimensions given. Draw the elevation of the lugs of both the light-frame and the dead cover. These lugs are each $\frac{1}{2}$ inch thick at the ends. That on the light-frame is flush with the inboard surface, and connects to the outboard face of the frame by an arc of $\frac{5}{8}$-inch radius. The lug on the dead cover is flush with the outboard face of the cover and connects to the circumferential stiffener web by a small fillet drawn freehand. The conical bearing surface is shown, $\frac{1}{8}$ inch deep and of $\frac{11}{16}$ inch small diameter, in both lugs and is concentric about the center of the dog.

Draw the dog $2\frac{7}{8}$ inches long from the center of the pin, and $\frac{5}{8}$ inch in diameter. A detached detail of the bottom of this dog is shown above on the plate. Draw the center line of this detail 1 inch, actual distance, from the left-hand border, and locate the center of the dog-pin hole $8\frac{3}{4}$ inches above the bottom border. Draw the center line of another view of this detail 1 inch below the center of the dog pin. The dog is seen to have a foot, or stop, so arranged that the dog will stand upright at 90 degrees to the port-frame. It can swing away from the port but not toward it. In the main section, draw the dog, dotting the part behind the lug.

79. Next draw the ring nut, or butterfly nut, piece **8**, to the dimensions shown on the section. The dog is threaded, seven to the inch, for a length of $2\frac{1}{8}$ inches from the end. The dog and threads are shown dotted where they pass through the lugs and the ring nut. A split pin $\frac{1}{8}$ inch from the end of the dog prevents the ring nut from coming off. The dog must be long enough so that when the ring nut is screwed up to the split pin, the ring nut, piece **8**, will clear the dead-cover lug when the dog is swung down, and the large opening in the upper part of the nut must be deep enough to allow the nut to screw far enough down on the dog to compress the gasket,

piece **7**, when the dead cover is swung out of the way. As shown, the gaskets are just in contact with the metal—not compressed. When the dead cover is swung out, the ring nut must be screwed down $\frac{1}{16}$ inch for contact with the light-frame lug, and, as laid out, there is a clearance of $\frac{13}{16}$ inch between the top of the dog bolt and the inside of the ring nut. The bottom of the ring nut is conical to fit the recess in the lugs.

80. In the main elevation, the lugs that hold the hinge pins of the dogs are shown dotted in the lower right and the lower left quadrants and they are completely dimensioned. The dog hinge pin, $\frac{3}{8}$ inch in diameter and 2 inches long, is secured by two $\frac{1}{8}$-inch split pins. In the two upper quadrants are shown the ring nuts, or butterfly nuts, in top elevation. The two pairs of diverging full lines represent the top. Cross-sections through the sides are represented by ellipses of $\frac{5}{8}'' \times \frac{1}{4}''$ major and minor axes. The large circle represents the base of the nut, which is $1\frac{1}{8}$ inches in diameter. The lines next to this circle are arcs that represent the top of the nut, $\frac{7}{8}$ inch in diameter, into which the sides of the handles merge at a thickness of $\frac{3}{4}$ inch. Note the method of giving the dimension with tapering lines. The other two circles are the bottom of the conical surface or the bottom of the nut, $\frac{11}{16}$ inch in diameter, and the bottom of the dog, $\frac{5}{8}$ inch in diameter.

81. In the upper left-hand corner of the plate is a detail of the dog used to hold the light-frame only. In this view, the center of the hinge pin of the dog is located $2\frac{1}{4}$ inches below the top border line and $\frac{7}{8}$ inch from the left-hand border; the section of the port-frame, light-frame, and retaining ring, pieces **1**, **4**, and **6**, are just as in the main section. A partial view only is given of the ring nut, piece **8**. The dog, piece **9**, is $2\frac{3}{8}$ inches long and is threaded for $1\frac{1}{16}$ inches. This can readily be drawn. The dimensions for the rubber-gasket slot in the light-frame are on this detail.

82. The lug that keeps the light-frame open is to be drawn on the horizontal axis of the frame in the elevation, and the center of the eye is $6\frac{5}{16}$ inches from the center of the port. The principal dimensions to be used in drawing this are to be

obtained from the detail view. In this the center of the eye is located $4\frac{1}{4}$ inches and $4\frac{15}{16}$ inches from the left and the top borders, respectively, and is shown to be $\frac{3}{4}$ inch inboard of the outer face of the light-frame. The eye is $\frac{3}{8}$ inch in diameter and the lug is $\frac{5}{16}$ inch thick. From these dimensions, the view on the horizontal center line of the elevation may be drawn. A small fillet drawn freehand is indicated where this lug joins the frame.

83. A similar eye is to be drawn on the bottom of the dead cover. A separate detail is also drawn in which the center of the eye is $5\frac{9}{16}$ inches and $8\frac{1}{8}$ inches, respectively, from the right and top borders.

The port-frame is secured to the steel structure by twelve $\frac{1}{2}$-inch tap bolts equally spaced on a circle $13\frac{1}{4}$ inches in diameter. Four are on the vertical and horizontal axes. A separate detail of this fastening is to be drawn with the inside of the plate $6\frac{1}{8}$ inches above the lower border and the center of the bolt $\frac{3}{4}$ inch from the left-hand border. The plate is shown $\frac{11}{16}$ inch thick, a small portion of the port frame, piece **1**, is drawn and the bolt is drawn standard size, see table of bolt sizes. The hole through the port-frame is indicated to be slightly larger than the bolt.

The addition of dimensions and the schedule of material and the title and number of the plate completes this drawing.

SKETCHING

INTRODUCTION

1. In actual office practice, the draftsman often has to work from rough freehand sketches. These sketches may or may not have been made by himself, and they may have been made from an actual object or may merely represent some one's idea on the particular subject which the draftsman now has to develop or work out. For instance, suppose that a machine is in operation somewhere, of which the drawings never existed or have been lost. For the purpose, say, of rebuilding or regularly manufacturing this machine, a set of working drawings is required. Suppose, as is most generally the case, that the machine is so located that it is not readily accessible to the draftsman at all times, so that he cannot take measurements while making the drawing, even if this were desirable. In such cases he must make **sketches,** that is, rough mechanical drawings freehand, from which later on he executes the regular drawings.

Again, suppose a certain change or modification is to be made in a machine, machine part, or mechanism, or a new machine is to be made, and a working drawing is required. The idea is then made clear to the draftsman by means of sketches, more or less complete, from which the regular drawings are subsequently elaborated.

2. A sketch must have all the essentials of a working drawing except that it is not made to scale, although the relative proportions of the object represented are maintained as near as this is possible by mere judgment of the eye. As in a mechanical drawing, the sketch must, of course, contain all the

dimensions and explanatory notes necessary to enable the object to be made from it. To all intents and purposes, then, a working sketch could be immediately used as a working drawing, and is sometimes so used in cases of emergency. A regular working drawing is, however, usually more elaborate; not only is it drawn to scale, but generally a smaller number of views of the object are made than are shown in a sketch. In both, one endeavors to get along with as few views as are necessary to clearly represent the object, although in a sketch a multiplicity of lines is avoided by additional views and sections, which can be quickly drawn; also, various notes, short cuts, and conventional marks may be used more freely on a sketch than would be tolerated on a regular drawing.

3. Method of Procedure.—In sketching an object, it is first fully represented in as many views as are necessary to show all the details; the measurements are taken afterwards and written in. This is by far the best plan, as much time may be wasted by trying to take measurements and write dimensions as one sketches. Furthermore, by first fully completing the sketch a better general knowledge of the object is gained, which will help in distinguishing between dimensions that are essential and those that are not. Of this more will be said later.

SKETCHING MACHINE DETAILS

GENERAL REMARKS ON SKETCHING

4. Materials for Sketching.—All that is needed for making a sketch are a lead pencil, paper, and a soft rubber. It is convenient to have the rubber attached to the end of the pencil. Various rubber-tipped pencils are in the market and are readily obtainable from stationers. The paper is best used in letter size, 8 in.×10 in., done up in pads, from which the single sheets can be detached one by one. The paper should be heavy, so that it will stand considerable abuse; manila paper is very good for the purpose.

5. Cross-section paper is of considerable assistance in sketching, and is often used in the drafting room by the designer when making sketches for the detail draftsman to work from. It is also an aid in maintaining the proportions of a detail. In the shop or other place away from the office, this paper is also a convenience, both in detailing the parts of a machine and in making a general view, because in the general view the ruled lines are a great help in drawing in the long outlines and serve to preserve symmetry and to insure the assembling of all the details in their proper positions. The beginner should, however, remember that a sketch is not a correct drawing to scale, and should not rely too much on the aid of cross-section paper, but should train his eye by practicing on plain paper, for he may often be called on to make a sketch when no cross-section paper is available, and without such practice he will find this difficult to do. All the sketches in this Section, therefore, will be described as made on plain paper except when it is expressly stated that cross-section paper is used.

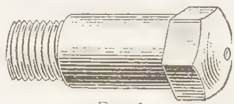


Fig. 1

Examples will be introduced to illustrate the use of cross-section paper in sketching, and it will be noticed that the order of procedure in making such sketches differs from that mentioned in Art. **3.**

Cross-section paper may be obtained ruled with spaces of various sizes. A convenient form has $\frac{1}{16}$-inch squares; another kind frequently used is ruled in $\frac{1}{8}$-inch squares.

6. Sketch of a Single Object Requiring But One View.—As previously stated, one should get along with as few views as possible; in some cases a single view will be sufficient for the sketch, while perhaps two might be called for in the working drawing made from it. Thus, the object illustrated in Fig. 1 can be fully represented by a side view, as shown in the sketch, Fig. 2; nor would the working drawing subsequently made from it require any more, since the view cannot be mistaken for anything else than a stud bolt with a hexagonal head. If the bolt had a square head, only one side

would be shown; the fact that two sides are shown in the sketch indicates that the head is hexagonal.

7. Sketching on Cross-Section Paper.—In Fig. 2 is illustrated the use of cross-section paper in making a sketch of the object that is shown in perspective in Fig. 1. In this sketch the letters are put on merely for descriptive purposes.

In sketching, as in every other kind of drawing, the main center lines should be put in first. Therefore, draw *A A* along one of the heavy lines, or simply indicate its selection as center line by putting a cross at each end. Then draw *a a* for the bottom of the bolt head locating each of the points *a* 8 squares

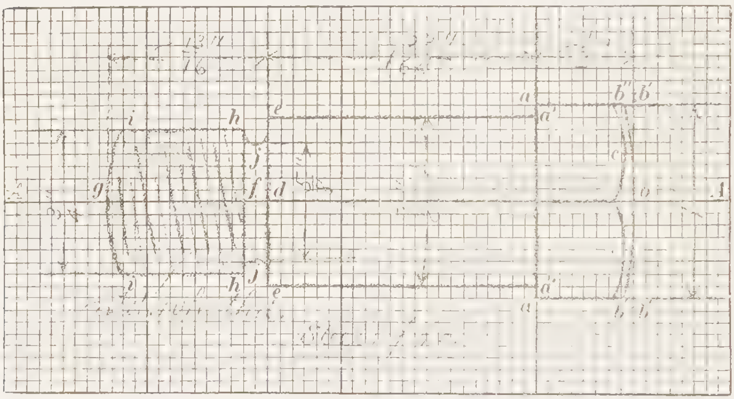


FIG. 2

above and below *A A,* since the size across flats is 1 inch. Show this view rather than that across the corners, because *across flats* is a governing dimension from which the one *across corners* will follow naturally. As the head is $\frac{1}{2}$ inch thick, mark off the point *b* a distance of 8 squares from *a a,* and draw a vertical line through *b*. Draw the horizontal lines *a b′,* and put in the curved line *b″ b b″* by eye, to represent the rounded form of the head, and next put in the two curved lines *c* representing the intersection of the flat faces with the top of the bolt head.

The body of the bolt is $1\frac{23}{64}(=1\frac{3}{8}-\frac{1}{64})$ inches long, consequently mark off on the center line the point *d* a distance of

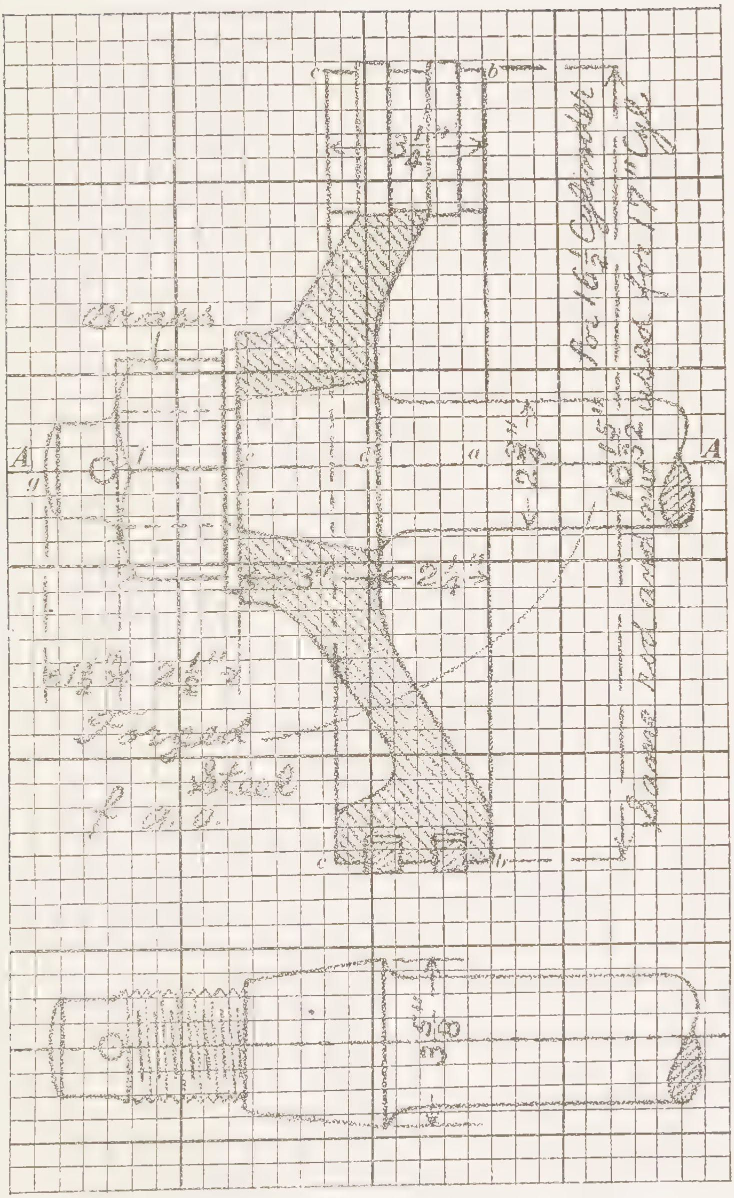


Fig. 3

one large square and six small ones from *a a*, ignoring the additional $\frac{1}{64}$, and then draw a vertical line through *d*. As the diameter of the body of the bolt is $\frac{7}{8}$ inch, set off from *d* two points *e*, each 7 squares ($=\frac{7}{16}$ inch) distance from the center line *A A*, and then draw the two lines *e a′*. Set off *d f* = 2 squares ($\frac{1}{8}$ inch) for the width of the clearance fillet, and next set off an additional 11 squares ($\frac{11}{16}$ inch) to obtain point *g*. Draw a vertical line *h h* through *f*, making each point *h* 6 squares ($\frac{3}{8}$ inch) distant from *f*, then round off the end *i g i*. Set off two points *j* 5 squares ($\frac{5}{16}$ inch) from *f*, and put in the fillets at *j*. Next sketch a conventional representation of the thread, and add any notes relating to material, finish, etc.

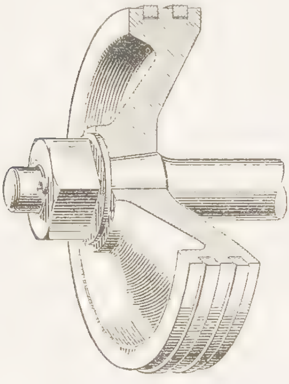


Fig. 4

8. Another illustration of the use of squared paper is given in Fig. 3, which shows a sketch of a piston, with a nut and a portion of the rod. Fig. 4 is a perspective view of such a piston with a piece broken away to show its construction. The cross-section paper employed is ruled with $\frac{1}{8}$-inch squares. Therefore, if the side of a square is taken to represent $\frac{1}{2}$ inch, the sketch is quarter size, or 3 inches to the foot, instead of being full size as in Fig. 2. Except for this and the difference in ruling, the method of sketching will be the same.

It will be supposed that an actual piston such as illustrated in Fig. 4 is to be measured up and a dimensioned sketch made. If the draftsman cannot have access to a loose rod, he must have this one removed so as to obtain particulars of the conical fit in the piston. First locate the main center line *A A*. Observation having shown that the piston is about $16\frac{1}{2}$ inches in diameter, count down from the top of the paper a distance of, say, 19 squares ($=9\frac{1}{2}$ inches) and draw *A A*. The inner face *b b* of the piston will be taken as a starting point. Adding together the dimensions from the end of the rod, one gets

$(1\frac{1}{2}+2\frac{1}{2}+3+2\frac{1}{4})=9\frac{1}{4}$ inches. Mark off a point *a*, 20 squares distant from the left-hand edge of the paper, and through *a* draw the vertical line *b b*. For the diameter of the piston mark off $16\frac{1}{2}$ squares ($=8\frac{1}{4}$ inches) above and below *a*. The width being $3\frac{1}{4}$ inches, draw the two lines *b c* $6\frac{1}{2}$ squares ($=3\frac{1}{4}$ inches) long. Halves and other fractional parts of a square are found by judgment only. Starting again from *a*, set off the lengths *a d*, *d e*, *e f*, and *f g* according to the dimensions shown. A few of the leading dimensions have been given as a check, also one or two of the notes that would naturally be added. The end of the rod may be sketched on the side, as shown, for convenience sake, with the large end of the cone on the same vertical line on which it is drawn in the view of the piston. The dimensions of the body of the piston have been omitted, as enough has been given to show the use of cross-section paper in sketching.

While the use of cross-section paper is an assistance in making a neat sketch of an actual machine detail, its most common use is in the office for roughly designing a part for a detail draftsman to work up.

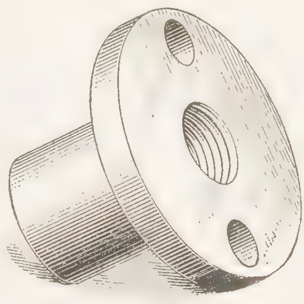


Fig. 5

9. Sketch of an Object Requiring One View.—Fig. 5 illustrates an object—a bushing—that might be sketched in a single view, as in Fig. 6, but would probably in a working drawing be represented by both a section and an end view, to show that the two rectangles in the sketch represent cylinders and that there are only two cylindrical holes in the flange. In the sketch, Fig. 6, the end view may be dispensed with and a note substituted giving the information about the holes. That the body is cylindrical may be indicated conveniently by adding to some of the measurements the letter D, meaning diameter. While such a view is sufficient, an end view alone would clearly not be, as it would not disclose the length of the two cylinders.

and would, even with the necessary information to that effect, be wholly inadequate to produce at once a mental picture of

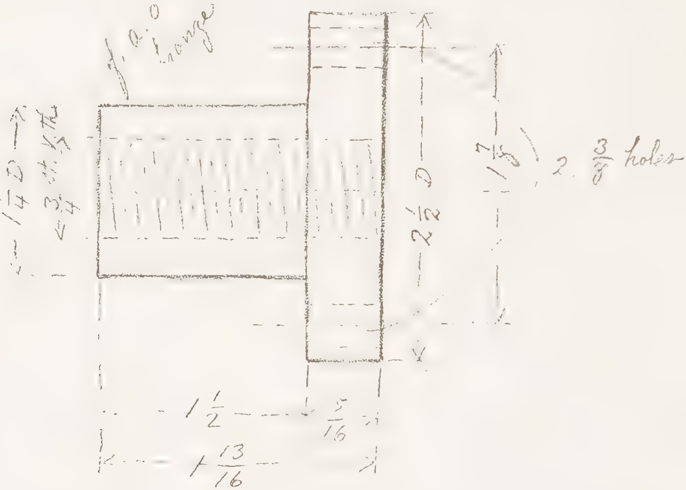


Fig. 6

the shape of the body. It is thus seen that judgment must be used as to what view to sketch. Rather than leave any doubts, two views should be made.

10. Sketch of an Object Requiring Two Views. Fig. 7 is an illustration of an object—a gripper from a printing press—that requires two views: a front view giving the peculiar outline of the piece, and an end view, or a bottom view, to show the width. See Fig. 8. While either the front view and the end view, or the front view and the bottom view, would suffice, an end view and a bottom view would not. The bottom view and the end view would not show the shape of the object.

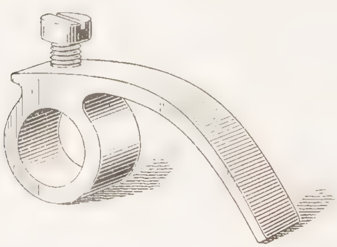


Fig. 7

The word **traced,** found on the sketch, means that the object was laid on paper and its outline penciled in. Where this is not practicable an **impres-**

sion may be obtained by holding the paper against the part and rubbing the finger along the edges.

11. Sketch of an Object Requiring Three Views. An object is represented in Fig. 9 that is simple in appearance.

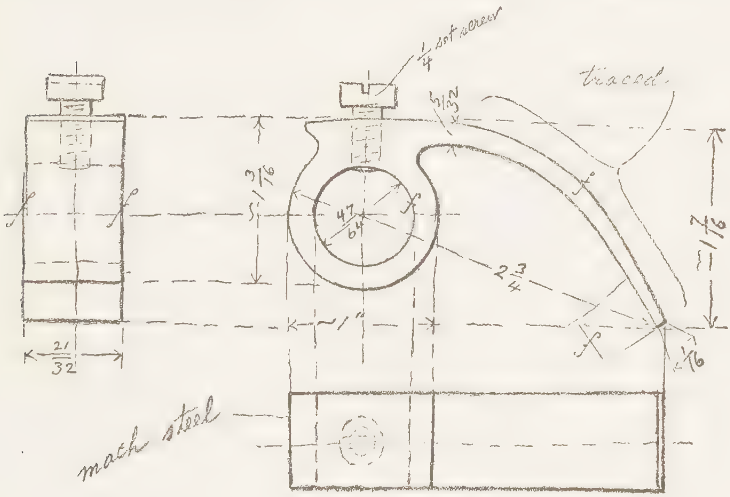


Fig. 8

However, it is necessary to show three views in order that the drawing may clearly bring out its shape. The front view in Fig. 10 is the main view; the side view and plan give the depth of the upright and base, and they also show, respectively, that the uprights and ends of the base terminate in semicircles. These are features the front view does not show.

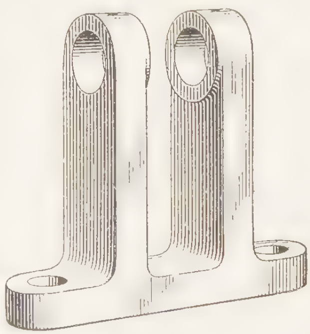


Fig. 9

12. Sketch of an Object Requiring a Section.—Three outside views will, as a general rule, be sufficient to clearly bring out the details of any object, even if the object is hollow and outlines are thus hidden from sight. In many cases, as, for instance, in the case of the bush-

ing shown in Figs. 5 and 6, dotted lines may be employed to point out such hidden features. Often, however, many dotted

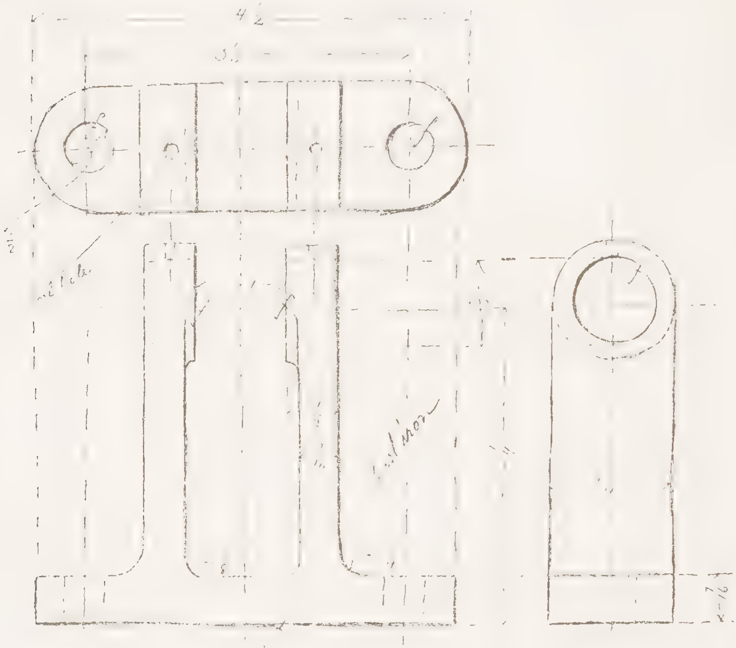


Fig. 10

lines become confusing, and it is then much better to make a section, that is, to imagine the object cut along a certain plane and one of the parts removed, a sketch being made of the remaining part. Fig. 11 is an example of such an object—a safety collar.

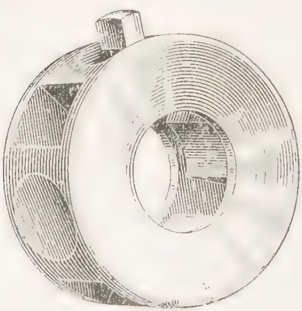


Fig. 11

A side view, and a front view, Fig. 12, give an idea of the outside features of the object, but in order to show the inside, a so-called conventional section has been taken along the lines *a b* and *b c* in the front view. This enables the draftsman to show both the rounded recesses and the tapering

square holes which have been cored out in order to make the casting lighter. It will be noted that a setscrew has been placed in one of the rounded recesses. When this setscrew is tightened

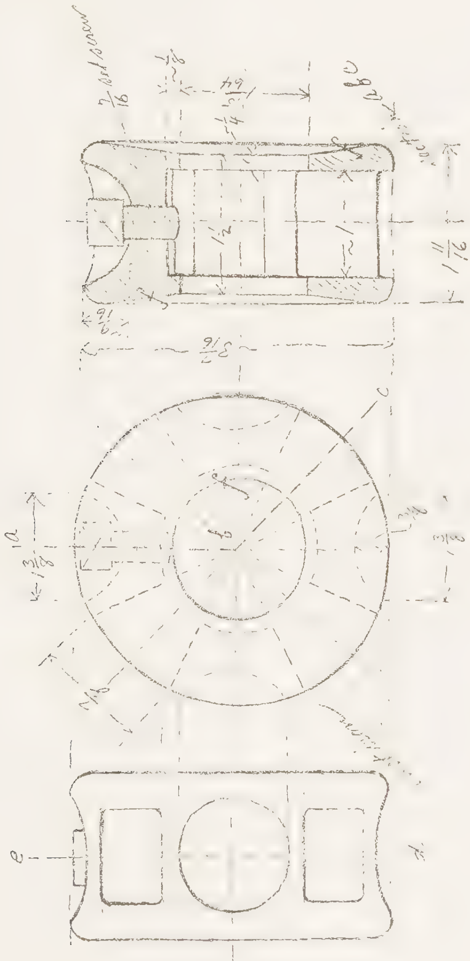


Fig. 12

the top of its head comes below the outside circumference, a feature of safety that prevents the screw from catching on the clothing of a workman. The section further shows that the collar bears against the shaft only at the outer and inner ends

of the shaft hole, the offset between leaving only a narrow surface at each end to be finished and fitted to the shaft. It also shows that the end surfaces are not level but incline toward the shaft hole. A section taken along the line *e d* in the side view would not show these features sufficiently.

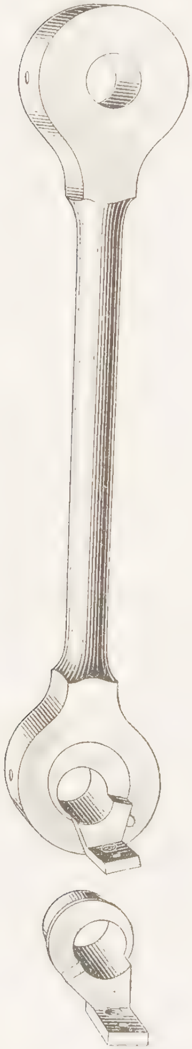
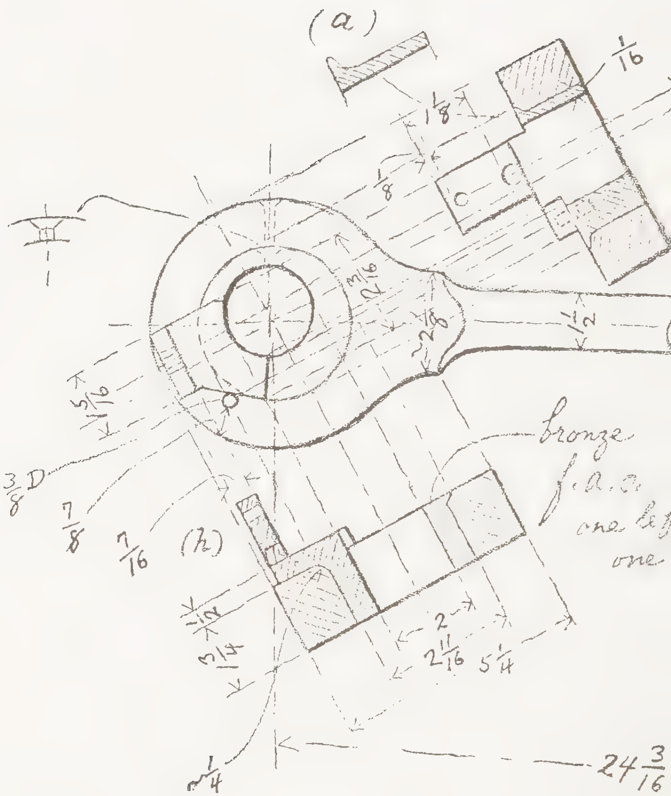
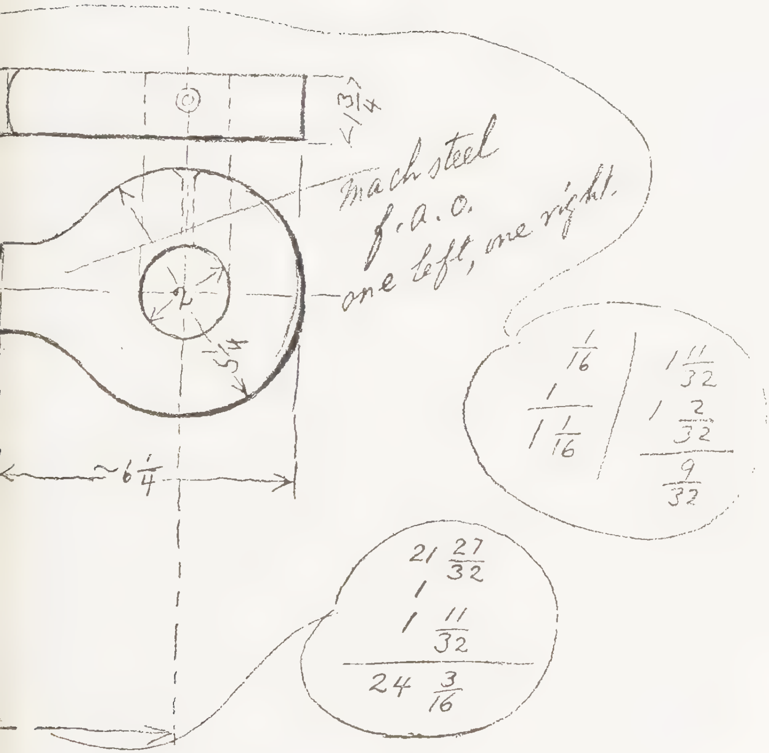


Fig. 13

13. Sketch of Two or More Objects Fitted Together.—When a combination of parts is to be sketched, such as an entire mechanism, it is advantageous in several respects to sketch them as a whole first. By so doing, a clear idea is acquired of how the various parts fit and work together, and many dimensions will have to be taken but once. After having gained all the information possible without taking the mechanism apart, each piece is removed one by one, and any additional features that may present themselves are sketched; these may even call for additional views. Fig. 13, which shows one of a pair of connecting-rods from a printing press, is an illustration. The two parts fitted together are the rod proper, having two eyes, one of which is provided with an eccentric bushing having a bracket of peculiar shape. In taking the view of the combination as a whole, the bushing was observed to have a larger outside diameter in the front than in the back. To find out how far into the eye the larger part extended, the bushing had to be slipped out, when it was seen that the larger diameter was due simply to a slender shoulder following the rounding of the edge of the eye of the rod proper, and a little sketch (*a*), Fig. 14, was jotted down to emphasize this. Otherwise, the two parts sketched together give all the information neces-



(a)
1/16
1 1/8
1/8
2 3/16
2 7/8
1/2
1 5/16
3/8 D
7/8
7/16
(b)
bronze
1/2
3 1/4
2
2 11/16
5 1/4
1/4
24 3/16



3/4
Mach steel
f.a.o.
one left, one right.
2
5 1/4
6 1/4
1/16
1
1 1/16
1 11/32
1 2/32
9/32
21 27/32
1
1 11/32
24 3/16

sary to draw them separately on the working drawing. The mate of the rod sketched is exactly the same with the exception that the $\frac{3}{8}$-inch pin is symmetrically opposite on the other side of the center line, and the bracket (h) of the bushing is reversed, as seen on the bushing, shown detached. In a case like this it is sufficient to mark on the sketch "one right, one left," the sketch thus covering four pieces at once. The abbreviation *f. a. o.* found on this sketch means "finished all over."

14. Fragmentary Views: Symmetrical Objects. Many objects present a repetition of parts, in which case it is sufficient to sketch only parts of such objects. This is particularly the case in objects that are symmetrical with reference to certain lines so that the sketch will also be symmetrical to such lines, which are called axes of symmetry. An **axis of symmetry** is any line so drawn that if the part of the figure on one side of the line be folded on this line it will coincide exactly with the other part, point for point and line for line. The use of fragmentary sketches must not, however, be carried too far. This expedient should only be employed when it saves time and the sketch would not be any clearer if the views were drawn in full. Thus, it would not be much of a saving of time to show only half of the bolt (Fig. 1), the bushing (Fig. 5), the gripper (Fig. 7), the bracket (Fig. 9), or the collar (Fig. 11), as these pieces, though they are symmetrical to a certain center line, are as easily sketched in full. Among the cases in which fragmentary sketches may be made are symmetrical machine frames, such as those shown in Fig. 15 and sketched in Fig. 16, or pulleys and other wheels, as those shown in Fig. 17 and sketched in Fig. 18.

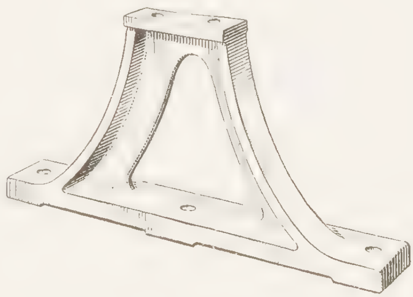


Fig. 15

15. Although in finished working drawings it is advisable, as far as convenient, to be consistent in the arrangement of the various views, yet, in sketching, the draftsman will be at liberty to place the views where most convenient for that particular

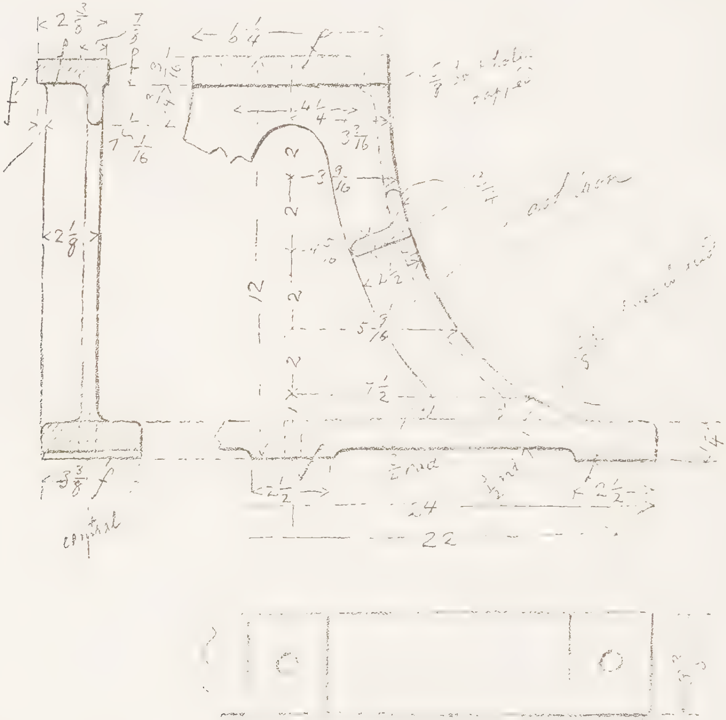


Fig. 16

case, making it perfectly clear by a note from what position the view was taken if there is room for any doubt on the subject.

16. Center Lines and Proportions.—In beginning a sketch, decide on a view that seems to show most of the features of the object. Select one of the most striking dimensions—as, for instance, the total length or total height of the piece to be sketched—and mark down on the paper a distance that represents this dimension. Then, until the sketch is completed,

this forms the basis for proportioning the other dimensions, by comparing them mentally with it. If the object is symmetrical about certain axes, draw these axes first. Thus, in round pieces like those shown in Figs. 1 and 5, draw the center line. Although measurements are not taken from these imaginary lines, they are of great help in guiding the eye while making the sketch. This is especially true in the case of circles. When more than one view of an object is sketched, the center lines at once serve to bring various views in proper relation to one another. Thus, in sketching the objects shown in Figs. 9 and 10, the front view is drawn first, starting with the center line, which divides the figure vertically into symmetrical halves. Next

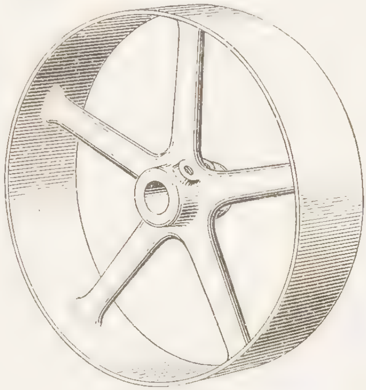


Fig. 17

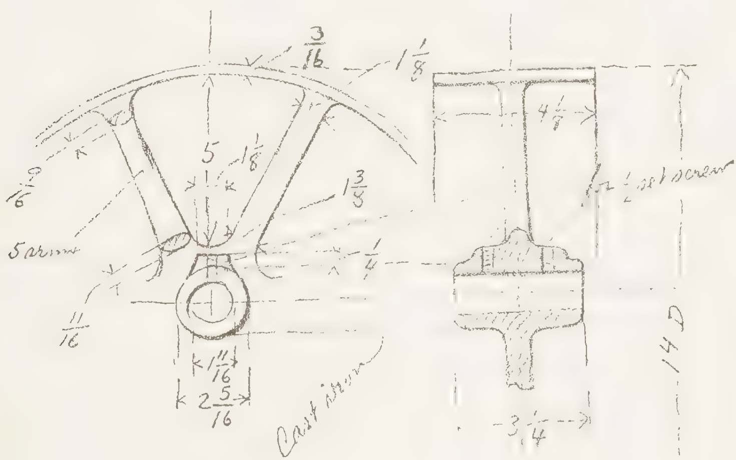


Fig. 18

draw the base line, and then the center lines of the bolt holes in the base at equal distance right and left of the main

center line; draw the center line of the shaft holes in the uprights parallel to and at the proper distance (judging by the eye only, of course) from the base line, and around this skeleton of center lines draw the outlines of the object. When the front view is finished, begin the plan. To do this, prolong the main center line, also the center lines of the holes in the base. Draw a horizontal axis of symmetry parallel to the base and the axis of the shaft, thus obtaining a skeleton of center lines for the plan around which to draw it. Proceed similarly with the side view, carrying over the center line of the shaft holes and drawing a new axis of symmetry parallel to the main center line of the first view.

17. Projection Lines.—In sketching various views of an object, use will be made of the principles of geometrical drawing, and projection lines will be drawn from one view to the other. Such lines should be indicated on the sketch very faintly, and should be limited in number, as they will make the sketch confused if used too freely or made too heavy.

18. Shade Lines.—It is not customary, as a rule, to employ shade lines on a working drawing. They are, however, sometimes used on sketches, as they tend to make the object stand out more clearly, without entailing much expenditure of time, and no artifice should be spared that will effect this, especially as a sketch may be laid aside a long time before the finished drawing is made.

19. Sections and Cutting-Plane Lines.—Sections must be placed in the sketch in proper position toward the lines of section along which they are taken. When the section is placed in its proper position, this fact will often prove sufficient to indicate along which line the section is taken, but in so-called conventional sections it is necessary to make the cutting-plane line very plain and to note near the sectional view the line of section, as was done, for instance, in Fig. 12. There are two sections in Fig. 14; one is taken on the center line passing through the center of both the eccentric hole of the bushing and the center of the eye of the rod; the other section is really a conventional section, the section of the eye being

taken on the center line passing through the center of the eye, and the section of the bushing being taken on the center line passing through its own center. There is no need of mentioning this on the sketch, however, as no one will suppose that a measurement is taken of the dimension of the eye along the line passing through the center of the eccentric bushing.

20. Cross-Sectioning to Indicate Material.—As, on a sketch, no distinction is made between materials by means of cross-section lines, the name of the material should be written on the sketch.

21. Finish Marks.—Finish marks should be placed in the sketch wherever lines represent finished surfaces, except in those cases where it is evident from the nature of the pieces that the surfaces must be finished, such as surfaces fitted together. The principle to be followed in making a sketch is, in general, give all the data necessary, but avoid unnecessary marks and lines.

MEASUREMENTS

MEASURING INSTRUMENTS

22. The instruments to be used in measuring the dimensions of an object for the purpose of making a sketch and subsequently a working drawing depend to a certain extent on the accuracy required. To explain more fully, suppose one of the eccentric bushings on the connecting-rod for a printing press, Fig. 13, to be so worn as to need replacing, but that the press is to be kept running while a new piece is being made. A very accurate measuring of the dimensions is then necessary, as the piece must fit exactly. On the other hand, suppose a whole machine is to be rebuilt with an already existing machine as a model, and that for this purpose drawings are to be made which henceforth shall be considered standard. The dimensions need not necessarily be as accurate as in the first case, as the various pieces of the new machine will be fitted together when assembling. In the former case, it may be necessary to employ much

more delicate instruments than in the latter case, so that, in general, it may be said that a draftsman may in the long run make good use of any measuring instrument to be found in the market. For ordinary cases, however, the tools here enumerated and described will be found amply sufficient.

23. The Two-Foot Rule.—The best-known tool for measuring linear dimensions is the two-foot rule, which is usually made up of four sections, hinged together, to allow it to be folded for convenience in carrying, as shown in Fig. 19. The rule is usually made of boxwood, with brass joints and edges. It is divided into inches and fractions of an inch. Divisions smaller than $\frac{1}{16}$ inch are rarely marked on them, so

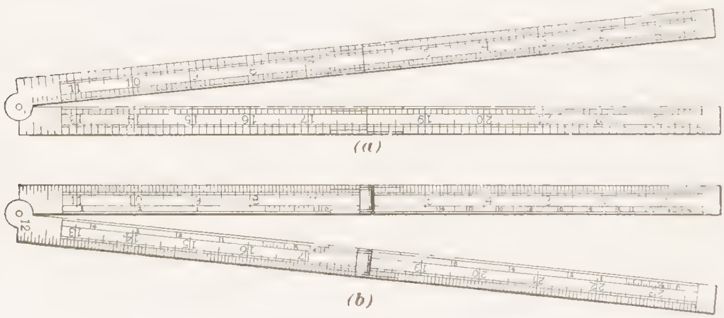


FIG. 19

that the smallest fraction that can be directly measured is $\frac{1}{16}$ inch, but with a little practice it is possible to locate the middle and quarter points between the sixteenth-inch marks with a fair degree of accuracy, thus making it possible to measure distances as small as $\frac{1}{32}$ inch and $\frac{1}{64}$ inch. The two-foot rule is well adapted to comparatively rough work, where only ordinary accuracy of measurement is required.

24. The Standard Steel Rule.—For more accurate measurements, steel rules are used. These rules are always graduated on both edges of each side, and a large choice of different kinds of graduations is offered by the makers. For use in sketching, two kinds of rules, both 12 inches long, will be found very essential. One has divisions of the inch into

8 parts on one edge of the one side, into 16 parts on the other edge of the same side, and into 32 and 64 parts on the two edges, respectively, of the other side. The other rule has divisions of the inch into 10, 20, 50, and 100 parts on the four edges, respectively.

25. Steel Tapes.—In measuring distances greater than a few feet, steel tapes are very convenient. They are made in lengths varying from 2 feet to 100 feet for shop use. The

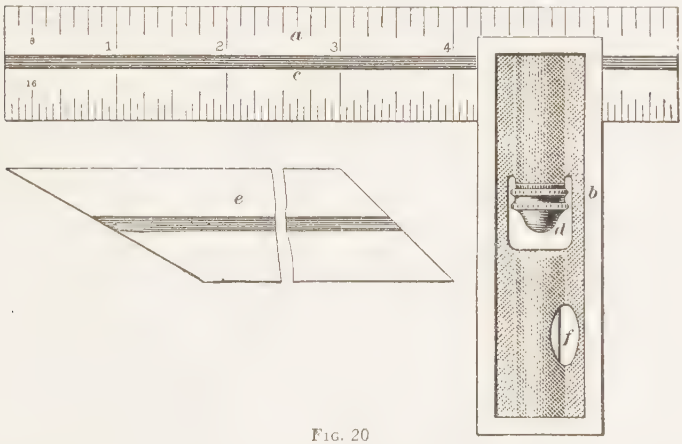


Fig. 20

graduations are not very fine; hence, tapes are only suitable for approximate measurements. For a special use of a pocket steel tape, see Art. **37.**

26. The Straightedge.—It is very convenient to have a straightedge among the tools, although any straight piece of metal or wood or the blade of a square (see Fig. 20) may be used in an emergency.

27. The Square.—An instrument that comes into frequent use is the square. It is best to have one with an adjustable blade, called an *adjustable square,* such as is shown in Fig. 20. The blade *a* is held in the stock *b* by means of a hook clamp that enters the groove *c* in the blade and is tightened by means of the nut *d*. The stock can be set at any point throughout the length of the blade, and also, of course, flush with the

end of it, thus serving also as a *solid square*. A special bevel blade e for testing angles of 45° and 30° is generally furnished with this square. The stock is usually provided with a level at f that may be used in testing either a vertical or a horizontal surface.

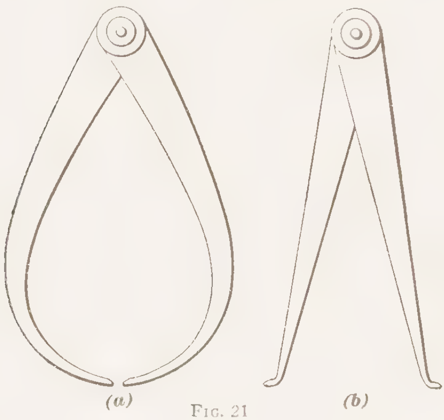


Fig. 21

It should be borne in mind that a square is perfect only when the blade and stock are exactly at right angles to each other, and that a fall or any careless use is liable to impair its accuracy, and its usefulness.

28. Calipers.—Calipers are of numerous shapes and sizes. They are used to measure either diameters or widths and

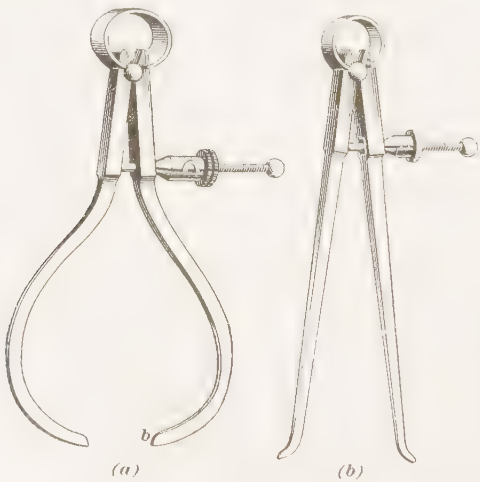


Fig. 22

lengths, from a small fraction of an inch to several feet. The simplest forms of calipers are shown in Fig. 21, where view (a)

illustrates *outside calipers,* used for taking outside measurements, of shafts, wheels, and similar articles, and view (*b*) shows a companion tool, the *inside calipers,* which, as the name implies, is used to measure the diameter of holes, or the distance between two objects. Another class of calipers is provided with an adjusting screw, as shown in Fig. 22 (*a*) and (*b*). Calipers are often used to measure the outside diameter of screws, and when so used are made as in Fig. 22 (*a*), except that the contact surfaces *a* and *b* are made wide enough to reach across two or more threads. Similar calipers are used to measure the bottom of screw threads, in which case the points are beveled and thin, like a knife blade.

Fig. 23

29. The Plumb-Bob.—The plumb-bob is often very convenient to have among the tools used in sketching, although any small piece of metal, as a nut, a penknife, or other small, heavy object tied to a thread does equally well in most instances, since it does not often happen in sketching that a plumb-line must be established over a certain point; in this latter case, a regular plumb-bob having a sharp point would be required, as shown in Fig. 23.

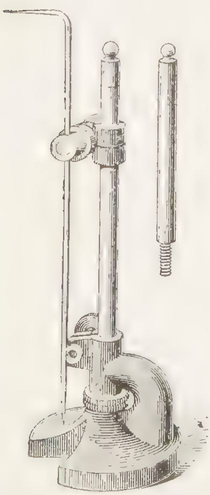


Fig. 24

30. Surface Gauge.—A surface gauge consists of a flat base to which is attached a vertical standard that carries an adjustable scriber. Fig. 24 shows a simple form of this instrument. Its use in sketching will be more fully treated in the following pages.

The draftsman is not expected personally to possess all the tools mentioned in Arts. **21** to **30.** In most drawing offices, certain of these tools would be supplied for common use, and the others would be borrowed from the shops for the occasion.

TAKING MEASUREMENTS

31. Writing Measurements on the Sketch.—After the sketch itself is completed—or when in a combination of objects fitted together, as a whole machine, the sketch has been completed as far as that is possible without taking the combination apart—the taking of measurements is begun. *Each measurement must be put down on the sketch as soon as it has been taken, not several at a time.* Otherwise mistakes are certain to occur, and to cause considerable trouble.

The ascertaining of dimensions of an object by measuring often calls for considerable ingenuity, and sometimes methods of the draftsman's own devising will be resorted to that are not found described in the following pages, which contain, however, those in most frequent use.

32. Distance Between Points on a Plane Surface. This is the simplest measurement; it is taken by means of the rule, and needs no explanation. Very frequently the points between which the dimension is wanted are the two edges of a flat surface. Such a measurement is required to determine the length ($6\frac{1}{4}$ inches) of the top of the stand in Fig. 16 and also the bottom of the base (24 inches).

33. Length of a Cylindrical Surface.—A measurement equally simple is to find the length of a cylindrical surface by means of the rule, as, for instance, the lengths ($1\frac{1}{2}$ inches and $\frac{5}{16}$ inch) of the two cylinders in Fig. 6, or the length of the shank of the tap bolt ($1\frac{23}{64}$ inches) of Fig. 2.

34. Round and Otherwise Undefined Corners: Distance Between Parallel Planes.—Distance must often be ascertained between points one or both of which may be imaginary, as, for instance, when there are round corners. In such cases the adjoining surface must be prolonged so that a sharp corner is established. For instance, the length ($1\frac{11}{16}$ inches) of the safety collar, Fig. 12, could not be measured directly with the rule, but the collar had to be placed between two flat surfaces, and the distance between the latter measured.

This was most conveniently done by laying the collar on a plane surface and using the adjustable square in the manner shown in Fig. 25.

In the same manner, the square must be used to get the over-all dimension ($1\frac{13}{16}$ inches) of the bushing shown in Fig. 6. See Fig. 26. As will readily be observed, this method is really equivalent to taking the shortest, that is, perpendicular, distance between two parallel planes.

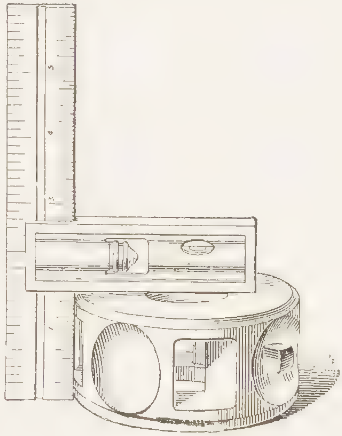


Fig. 25

35. Thickness.—It is not always convenient or possible to measure distances between parallel planes, real or imaginary, by means of the plane surface and adjustable square, in the manner shown in Figs. 25 and 26. In such cases, the outside calipers are used; thus, while the distance across flats of the hexagonal head of the bolt, Fig. 1, may be measured with the plane and square, it is more convenient to use the calipers, while the thicknesses ($\frac{3}{4}$ inch) of the webs in the cast-iron stand, Figs. 15 and 16, must be measured with the outside calipers, if the measurement is to be accurate, the corners being round. Such dimensions are called *thicknesses*.

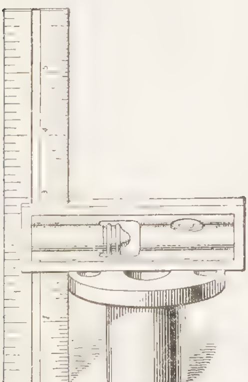


Fig. 26

36. Distances Between Curved Surfaces: Outside Diameters.—The outside calipers are also used to ascertain dimensions of curved surfaces. Thus, the dimension ($1\frac{3}{16}$ inches) between the top and bottom of the piece shown in Fig. 8 is measured with the outside calipers. As a rule, all outside diameters would be measured with the same instrument. The procedure is as follows: Open

the calipers approximately wide enough to let the body to be measured pass freely between the points. Then, by gently tapping the outside edge of one of the caliper legs against some convenient object, the calipers may be gradually closed or opened until the points just touch the body measured, as in Fig. 27. There should be no play, nor should the points pinch too hard. It requires a little practice to get the proper touch by tapping the calipers. The process is easier with spring calipers, having screw adjustment, shown in Fig. 22.

Fig. 27

After the calipers are properly adjusted, the distance between the points is measured with the steel rule in the manner shown in Fig. 28.

37. It often happens that very large diameters are to be measured, for which the calipers available are too small, as in the case of pulleys, wheels, and similar objects. Often in

Fig. 28

such cases one can measure near enough across the side of such objects, as a pulley, for instance, with a long rule or a

stick, but equally as often this cannot be done on account of other parts being in the way; for instance, when a pulley is keyed to a shaft, perhaps near to a hanger besides. In most cases the steel tape furnishes excellent means for getting at the diameter, by measuring the circumference of the wheel or pulley and dividing the same by 3.1416. Thus, if the circumference as measured with the tape is 7 feet $\frac{3}{4}$ inch, the diameter is $7'\ \frac{3}{4}'' \div 3.1416 = 7.0625' \div 3.1416 = 2\frac{1}{4}$ feet, very nearly = 2 feet 3 inches.

38. In the absence of a tape, the diameter of a wheel or pulley can be obtained by measuring from a point on the circumference of the shaft to a point on the rim of the wheel or

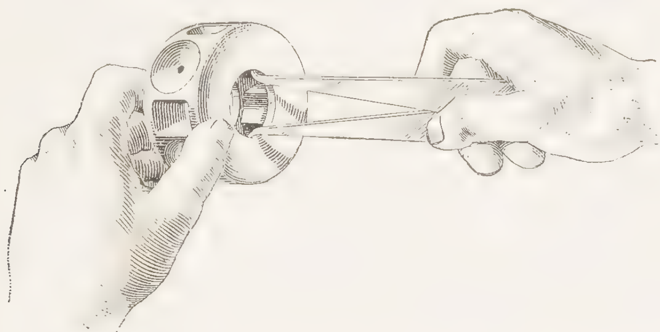


FIG. 29

pulley and adding twice this amount to the diameter of the shaft as measured with outside calipers. Care must be taken that the measurement is correct by moving the rule slightly in an arc and watching the greatest reading where the rim edge intersects the rule. This will serve as a check to determine when the rule is held radially.

39. Inside Dimensions: Holes.—To measure inside dimensions, such as the diameters of holes, for instance, the inside calipers are used, as in Fig. 29. The procedure is identically the same as with outside calipers, but care must be taken in tapping the instrument not to strike on the points, as these will be easily injured thereby. After the instrument is adjusted, the distance between the points is again measured

with the rule, as shown in Fig. 30, by holding the end of the rule up against some smooth, flat surface, whenever practicable, and then letting the point of the caliper leg press up against this surface.

40. Over-All Dimensions.—When the length of an object is measured in successive steps, as, for instance, the bushing, Fig. 6, it is best also to measure the whole length, which then serves as a check on the measurements previously taken.

41. Exact and Approximate Dimensions.—In the case of most objects, some dimensions must be exact, while others may be approximate. Thus, in Fig. 2, the length ($1\frac{23}{64}$ inches) of the shank of the bolt must be measured exactly, as the bolt is to be fitted into the eye of a lever that must move freely, without undue play between the shoulder of the head and the piece into which the bolt is screwed. Suppose that the bolt had been broken off at the screw and a new one was to be made; then it is evident that the shank of the old bolt must be very carefully measured so that the new one will exactly fit the length of the lever eye. The other lengths, that is, the extreme height of the head ($\frac{1}{2}$ inch) and the length of the screw to the top of its rounded end ($\frac{13}{16}$ inch) are clearly not so important. It is permissible to round off such unimportant dimensions to the nearest $\frac{1}{32}$ inch or even $\frac{1}{16}$ inch, as the case may be. Thus, suppose the length of the screw, Fig. 2, actually measured $\frac{51}{64}$ inch, it would be considered correct enough to mark this dimension $\frac{13}{16}$ inch on the sketch. Other examples are the width and thickness of the base and uprights of the

Fig. 30

object shown in Figs. 9 and 10. The piece is a casting finished only at the surfaces marked *f*, *f*. The actual measurements showed the thickness of the base to be between $\frac{13}{32}$ inch and $\frac{15}{32}$ inch and the thickness of the upright varied between about the same figures. This was evidently due to the shaking of the pattern in the mold, and the thickness intended was no doubt $\frac{7}{16}$ inch, so this measurement was marked on the sketch. Likewise, the radii of the fillets joining the uprights and base were "guessed at" more or less (see Art. **48**) to be $\frac{1}{4}$ inch and $\frac{1}{8}$ inch, respectively. Dimensions that have been thus rounded off, averaged, or more or less arbitrarily fixed may be marked with a little wavy line preceding the figures. See Figs. 10, 14, etc. When obtaining particulars for close fits (running, forced, etc.), micrometer measurements are necessary.

42. Establishing Centers.—Distances between two centers, as of two shafts, two holes, or distances between a center and a surface, etc., cannot in the majority of cases be measured directly with any of the instruments, and it requires considerable ingenuity and care at times to establish such dimensions. The following are a few examples.

A case very frequently occurring is the establishing of the distance between centers of two holes, as, for instance, in the connecting-rod, Figs. 13 and 14. This dimension ($24\frac{3}{16}$ inches) is here obtained by measuring the distance between the inside edges of the holes ($21\frac{27}{32}$ inches), and adding to this measurement half of the diameter of each hole, measured with the calipers, the results being $21\frac{27}{32}'' + \frac{2''}{2} + \frac{2\frac{11}{16}''}{2} = 21\frac{27}{32}'' + 1'' + 1\frac{11}{32}'' = 24\frac{3}{16}$ inches. Fig. 13 also furnishes another illustration: to find the distance between the center of the outside circle of the eccentric bushing and the center of the inside circle, that is, the eccentricity of the two circles, measure the thickness of the bushing at the thinnest part ($\frac{1}{16}$ inch), add to it half of the diameter of the inner circle, and deduct this sum from half the diameter of the outside circle; thus, $\frac{2\frac{11}{16}''}{2} - (\frac{1}{16}'' + \frac{2}{2}'') = 1\frac{11}{32}'' - (\frac{1}{16}'' + 1'') = 1\frac{11}{32}'' - 1\frac{1}{16}'' = \frac{9}{32}$ inch.

43. If the holes are of the same size, the distance between centers is at once obtained by measuring from the outside edge of one hole to the inside edge of the other, as, for instance, the distance $3\frac{1}{4}$ inches between centers of bolt holes in Fig. 10, and $4\frac{1}{4}$ inches and 22 inches in Fig. 16. Similarly, the distance between the center of the shaft holes in the object, Fig. 9, and the bottom of the base is obtained by measuring the distance from the bottom of the hole to the bottom of the base and adding to this the radius of the hole. The first dimension is, however, not directly measurable with a rule, but must be gotten by prolonging the bottom line of the hole by means of some convenient straight piece and the square, as shown in Fig. 31. This straight piece should preferably be round in section, as its under edge will then more accurately represent the prolongation of the bottom line of the hole; however, a straightedge, if quite thin, may be used by exercising care. At first sight it might seem as if this dimension might have been taken more easily by measuring the total height of the piece and deducting from it the thickness of the metal on top of the hole and the radius of the latter; but this would not give a reliable measurement, as the piece is not finished on top, while the

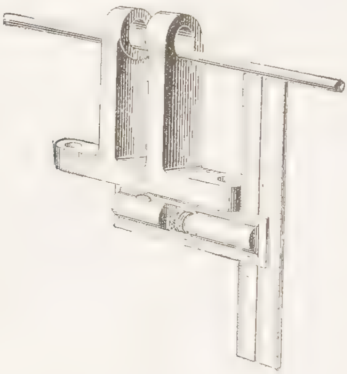


Fig. 31

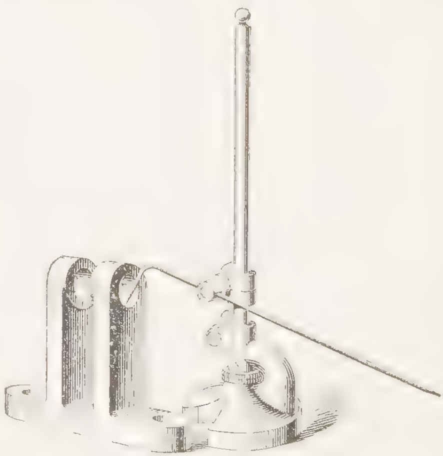


Fig. 32

bottom is, and as the dimension sought is an essential one, it must be accurate. An easier way to get the measurement, however, is by the use of the surface gauge. The gauge is adjusted so that the point of the scriber lightly touches the bottom of the hole; the scriber is then removed and the distance from the plane to the point measured. See Figs. 32 and 33.

Another example of finding the distance of a center from a plane surface is shown in Fig. 34. The adjustable square is used to find the distance from the top of the frame of the machine, which is finished, to the top of the collar below. To this is added half of the diameter of the collar, ascertained by means of the outside calipers.

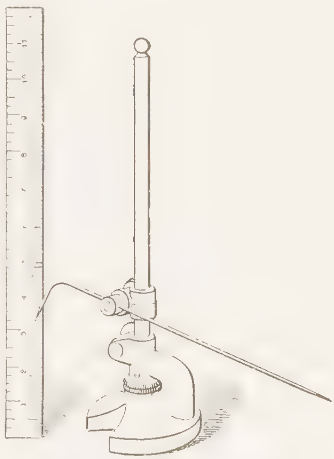


FIG. 33

A further example is given in Fig. 35. It was required to measure the horizontal distance of the center of the shaft from the vertical finished front of the machine. The square could not be used in the same manner as in Fig. 34, as the sliding carriage, already in its lowest position, was in the way. The dimension had thus to be transferred higher up, as it were. The plumb-bob was conveniently suspended, so that the plumb-line just touched the left side of the disk. Next, the distance between this line and the front of the machine was measured and one-half of the diameter of the disk added thereto. Before this method could be employed, however, it had to be ascertained whether the machine so stood on the floor that the front surfaces of the frame were vertical. It was found not to be the case, and it had to be wedged up on one side to make it so.

44. Centers of Gear-Wheels: Pitch of Gears.—The distance between centers of two gear-wheels in mesh must be measured with particular accuracy, as it furnishes the only

clue to ascertain accurately the pitch of the gears. If the shafts are accessible, either in front of or behind the gears, the distance between centers is easily established by measuring the distance between the shafts by means of inside calipers if the distance is short, or by means of two steel rules slid one upon the other, if the distance is greater. See Fig. 36, wherein the visible portion of the underlying rule is shown shaded. To this measurement the radii of the shafts are added. If the shafts are flush with the wheels, so that the distance between

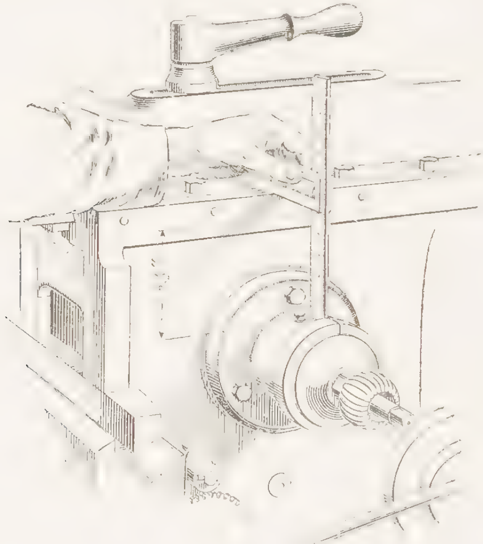


FIG. 34

centers cannot be measured in the above way, and if there are no hubs to make use of, the distance may be obtained by measuring across the wheels themselves and deducting their outside radii. This method will be absolutely exact only, however, if the number of teeth in both wheels is even, because, if the number is odd, the outside diameter cannot be measured accurately with the calipers; there is a tooth on one end of the diameter and a space on the opposite end, the measurement being between the point of the tooth on the one end of a diameter and the point of the tooth next to the space at the

other end of the diameter. The difference between the dimen-

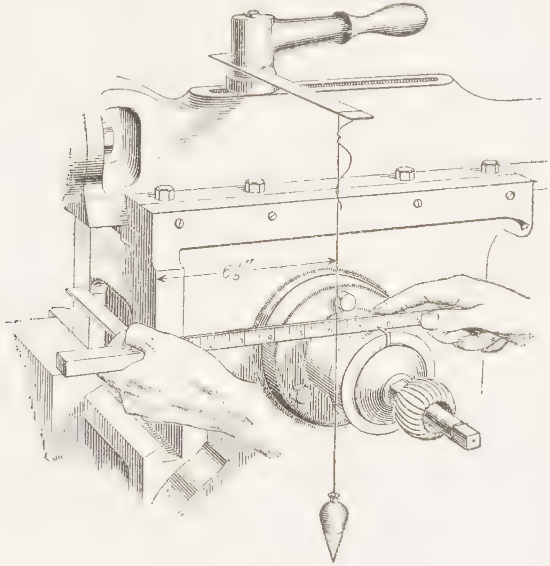
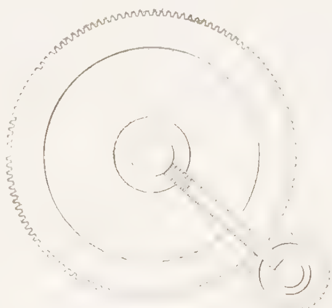


FIG. 35

sions obtained in this way is, however, but very slight in ordinary cases.



45. Having by some means ascertained the distance between centers, the diametral pitch* is found by dividing the sum of the teeth of both wheels by double the distance from center to center, and the circular pitch† by multiplying double the distance from center to center by

*The diametral pitch is a number indicating the ratio between the number of teeth and the pitch diameter; thus, 4 (diametral) pitch means that there are four teeth to each inch of the diameter, so that a wheel that has this pitch and has a pitch diameter of 5 inches has $5 \times 4 = 20$ teeth, or a wheel that has 20 teeth and a diametral pitch $= 4$ has a pitch diameter of 5 inches.

† The circular pitch is the linear measure on the pitch circle from a point on one tooth to the corresponding point on the next tooth.

3.1416 and dividing the product by the sum of the teeth of both wheels, or by formulas:

$$\text{diametral pitch} = \frac{N+n}{2c},$$

$$\text{circular pitch} = \frac{6.2832c}{N+n},$$

in which N = number of teeth of large wheel;
n = number of teeth of small wheel;
c = distance from center to center.

By calculating both pitches, it is generally recognized by what system they are constructed. Thus, if the calculation yields, for instance, a whole number, or a whole number and a half, or a whole number and a quarter, for the diametral pitch, but an awkward decimal number for the circular pitch, it is fair to assume that the gears are cut to the diametral pitch indicated by that number. If the calculation yields an awkward decimal number for the diametral pitch, but a whole number, or a whole number and simple fraction for the circular pitch, it is fair to assume that the gears are cut to circular pitch.

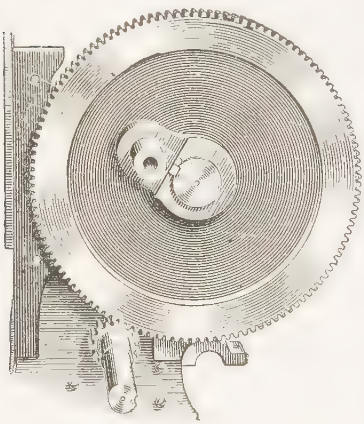


Fig. 37

Thus, the distance between the gears, Figs. 37 and 38, is by measurement $11\frac{37}{64}$ inches (= 11.578 inches +) from center to center. There are 15 teeth in the pinion, or small gear, and 124 teeth in the large gear. The diametral pitch is thus

$$\frac{124+15}{2 \times 11.578} = \frac{139}{23.156} = 6.003, \text{ or } 6, \text{ very nearly.}$$

The circular pitch is $\frac{6.2832 \times 11.578}{124+15} = .5233$ inch, that is, between $\frac{33}{64}$ inch and $\frac{17}{32}$ inch.

It is thus very evident that the gears are cut to 6 diametral pitch. As a check, using 6 for the diametral pitch, the distance from center to center is:

Pitch radius of large wheel + pitch radius of pinion $= \frac{1}{2}\left(\frac{124}{6}+\frac{15}{6}\right)=\frac{139}{12}=11\frac{7}{12}''=11\frac{37\frac{1}{3}}{64}''$, as against $11\frac{37}{64}''$ from actual measurement, the difference being only $\frac{1}{3}$ of $\frac{1}{64}''$, or $\frac{1}{192}''$.

In taking dimensions of gear-wheels, it is generally more exact to measure with a rule having inches divided into 100 parts.

46. The method of finding the pitch from the distances between centers is the only exact one, but cannot always be

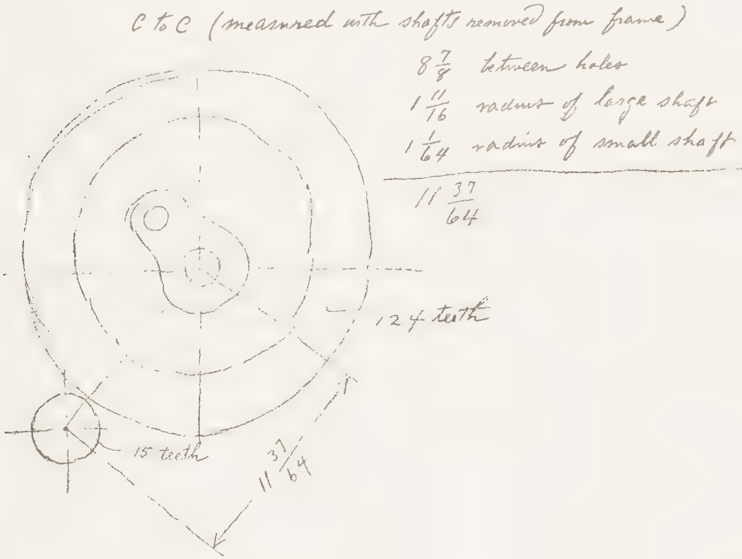


Fig. 38

employed; in many cases, the circular pitch must be measured directly at the point where the two wheels are in mesh, guessing more or less at the location of the pitch line; this can be fairly accurately done, however, since the teeth touch at the pitch line when passing through the line connecting the centers of the wheels. This method must be employed invariably

with miter and other bevel gears; it should always be employed as a check.

47. Curved Outlines: Fillets.—When curved outlines occur in frames of machines, they sometimes give considerable trouble in sketching. Fortunately, the dimensions are in such cases seldom required to be exact, and the measurements can be rounded off. The frame, Fig. 15, is an example. To get

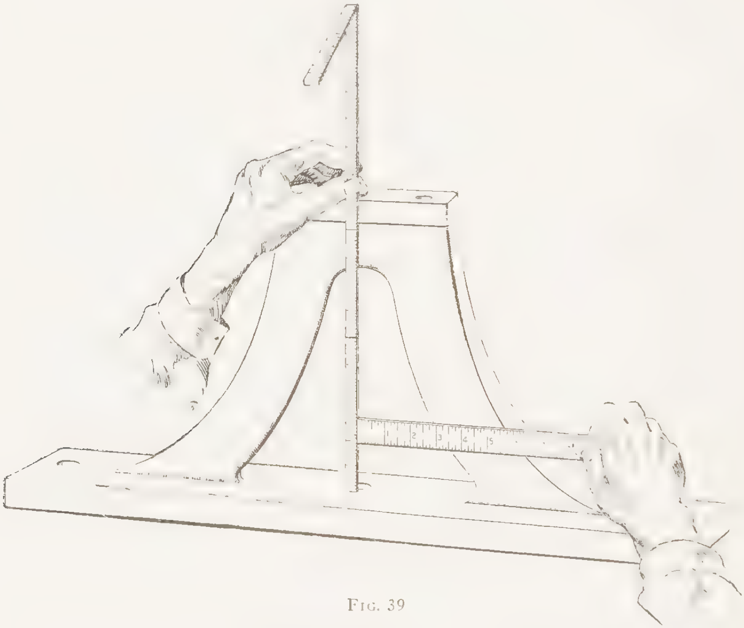


Fig. 39

the curved outline of the stand, the two-foot rule was held vertically in the center and horizontal measurements taken at various points of the rule, as illustrated in Fig. 39.

48. Sharp corners are avoided in machine frames whenever possible, being rounded off by fillets. It is generally sufficient to measure the radius of such fillets approximately. Small ones may be judged entirely by the eye, by placing the rule against the surface of the object where one end of the curve begins and reading off the length to a point that appears to be just in line with the other end of the curve. See Fig. 40.

Large fillets are best measured by means of the rule and square, by placing, as before, the rule against one surface of the object where the curve begins and the square on the other surface, and sliding it against the rule until both indicate the same distance; as illustrated in Fig. 41.

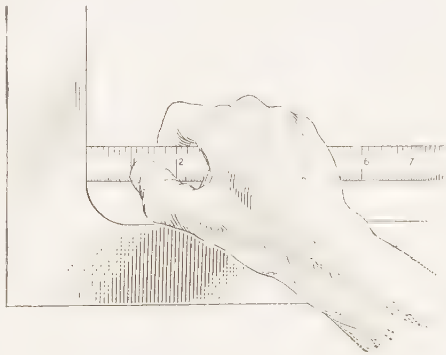


FIG. 40

There are cases, however, in which it is essential to get a curved outline exactly. In such cases it is best, if possible, to trace the outline by placing the object on the sketching pad and running the pencil point along the curves, as was done with the curved piece, Figs. 7 and 8. Evidently this method cannot always be resorted to, as, for instance, when the object is large or when the curve is so located on the object that it cannot be traced. The cam shown in Fig. 42 is an example. In such cases nothing short of a templet, made of stiff paper or even tin plate, will suffice. The sheet is placed over the curve and by gentle taps with the hand or a peen hammer the outline is transferred.

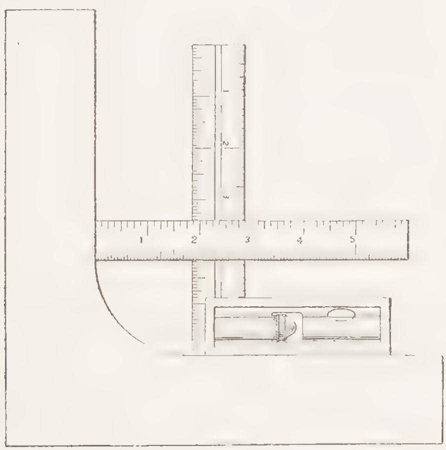


FIG. 41

49. Sketching a Machine Casting.—The tailstock casting selected for the sketch shown in Fig. 43 and of which

Fig. 44 is the finished drawing, is shown in perspective in Fig. 45. This is the same tailstock described in *Mechanical Drawing,* Part 3, in the chapter on Reading a Working Drawing. A cast-iron frame with its cored-out portions and its reinforcements of metal in the form of webs and bosses often taxes the ingenuity of the draftsman when he has to make a fully dimensioned sketch. Many shapes are hidden and difficult of access and the object must be carefully studied and examined before such details can be outlined and dimensioned. Such a study of an actual machine detail is very similar to the reading of a working drawing.

Fig. 42

50. The casting was first sketched in its entirety, in three views: an end elevation, a front view, and a partial top view, or plan. The end elevation and the front view were sketched in conjunction with each other, and the top view was sketched last. In order to understand the sketch better, it should be studied with reference to the perspective views of the complete tailstock shown in Fig. 45 (*a*) and (*b*). A section of the casting, taken between the barrel and the base, is shown in perspective in Fig. 45 (*c*). This section, in connection with view (*b*), shows clearly the construction of the upright part of the frame that supports the horizontal barrel. By first locating the horizontal and vertical center lines, the three views were brought in proper relation to one another, and they were sketched complete before being dimensioned. A study of the sketch will show what dimensions are needed for a finished working drawing, and the same dimensions which are marked on the sketch also appear on the finished drawing. The methods employed in taking the measurements of the tailstock for use on this sketch were similar to those that have already been described.

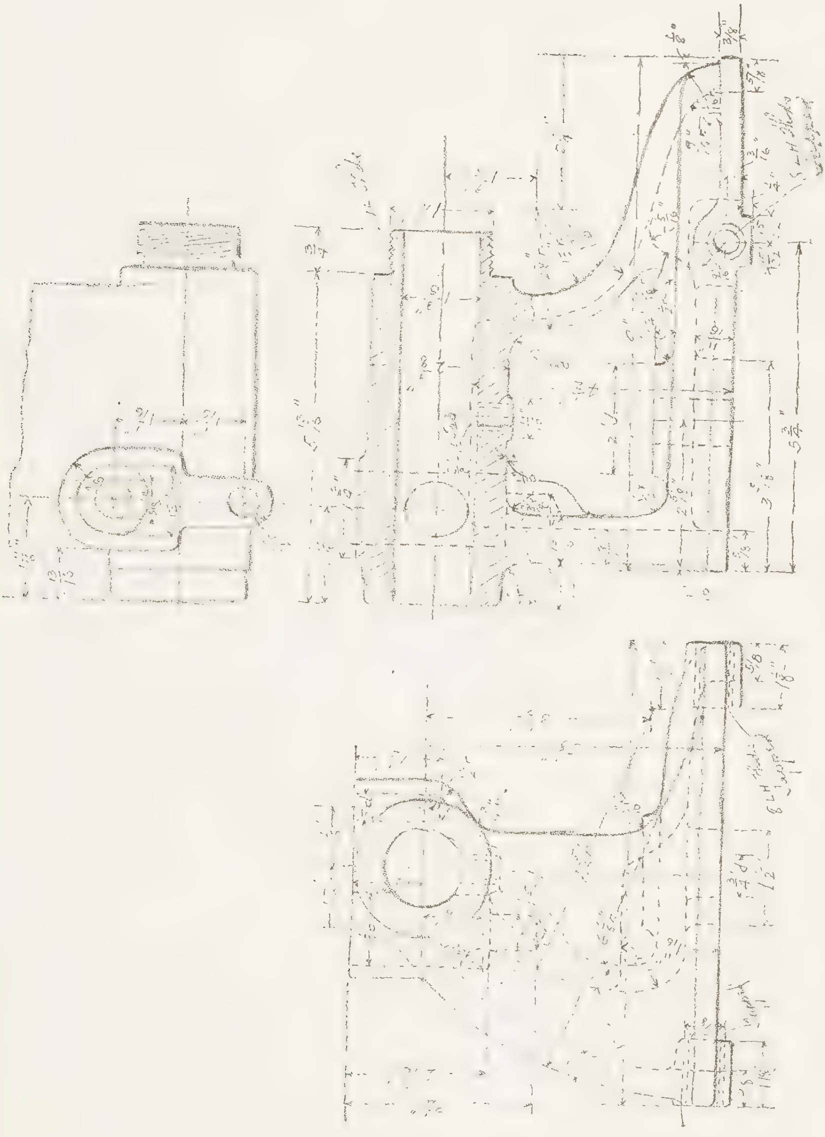


FIG. 43

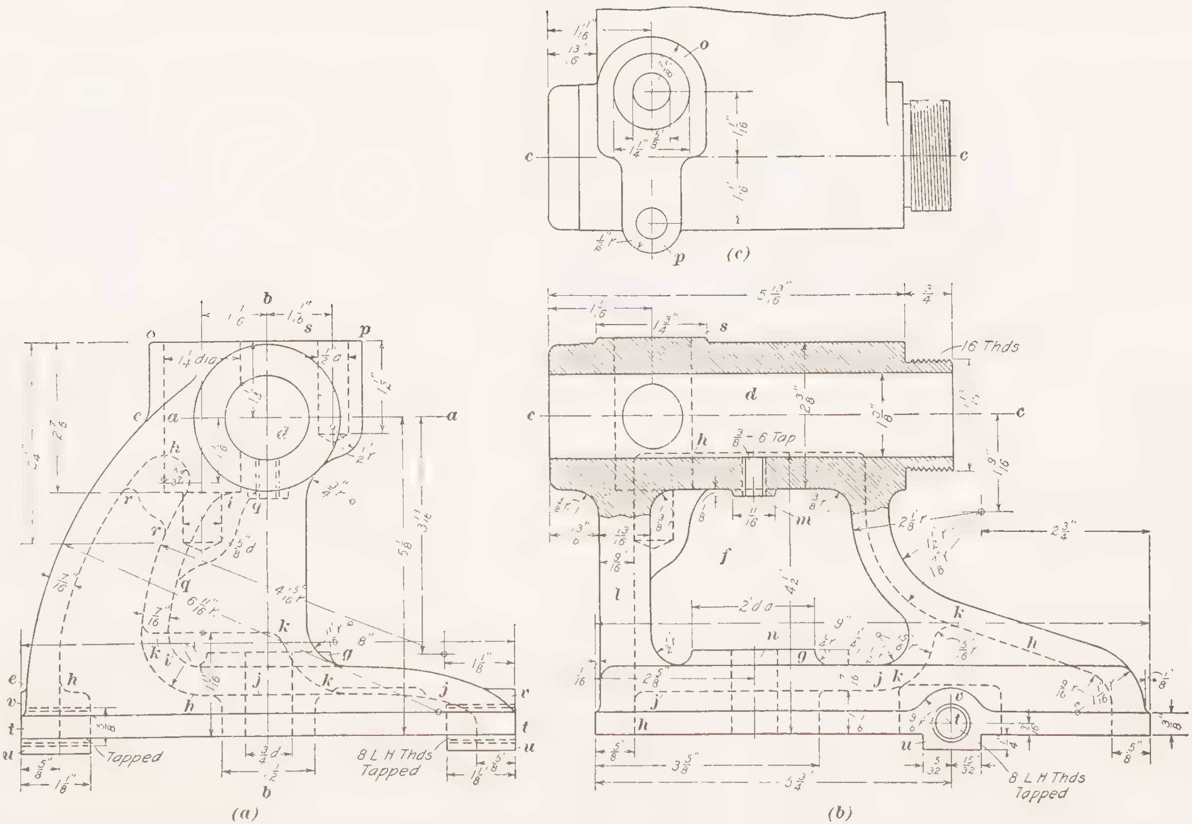
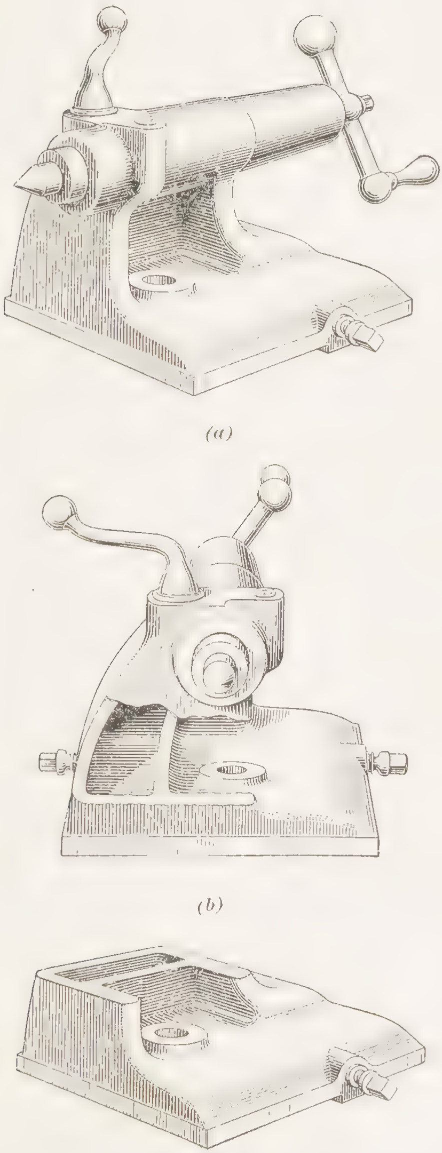


Fig. 44

51. Sketching Complete Machines. To sketch a complicated machine requires a considerable amount of experience and is something that is very seldom undertaken in present-day practice. After the necessary views of the machine have been sketched, the various measurements are obtained, those being taken first which can be ascertained without removing any of the parts. Most of the outside dimensions, either of the frame or of parts fastened to it, are obtained at this time, also the distances between shaft centers and their heights above the base lines, etc. After obtaining as many dimensions as possible without dismantling the machine, and especially dimensions which are common to pieces fitted together, one part after another has to be taken off to get at other dimensions. The taking apart must be done very carefully, so as not to miss any detail, however small,



(a) (b) (c)

Fig. 45

that is of importance. Whenever necessary, separate sketches are made of parts that would be represented on too small a scale in the main views to be clearly seen. When a separate sketch is made on the same sheet on which the main view is sketched, a line should be drawn from the separate detail to the main view, indicating the place where it belongs. If the detail is sketched on a separate sheet, a note with reference letters should indicate its position on the main view.

It should be remembered that the various dimensions are rarely written more than once on the sketches, and that dimensions of one and the same part may often be found in entirely different places, perhaps in connection with the part to which it is to be fitted. It is therefore necessary that the draftsman clearly understands the construction and function of the machine before he attempts to lay out a drawing from the sketches.

CONCLUSION

52. It is advisable to practice sketching at every opportunity. Any convenient object may be sketched, as, for example, a monkeywrench, a table, a vise, parts of a sewing machine, etc. The kitchen stove or a wagon will present considerable difficulty. No matter what the object may be that is sketched, it must always be kept in mind that every sketch must be so made and dimensioned that a working or finished drawing can be made from it without the necessity of seeing the object again. Hence, it is advisable not only to make sketches of convenient objects, but also to make at least pencil drawings from these sketches. The making of the drawings will reveal any omissions or defects in the sketches, and will afford the best kind of practice.

After a certain degree of proficiency has been attained and confidence gained, it will be of great value if permission can be obtained at some machine shop or similar place to make sketches of small machines and tools. Then, when one obtains employment as a mechanical draftsman, the work will be found comparatively easy, and advancement more rapid.

PRACTICAL PROJECTION
(PART 1)

FUNDAMENTAL PRINCIPLES

INTRODUCTION

DEFINITIONS

1. When any artisan or mechanic is required to make some article, it is evident that at least a verbal description of the article must be furnished. This verbal description of the thing to be made must not only give a clear idea of its form but of its dimensions as well, and also specify the kind and quality of material to be used in making it. Verbal descriptions of even very simple articles rarely prove satisfactory, as they are easily misunderstood; furthermore, in case an error is made, it is difficult to place the responsibility for the mistake where it belongs. Hence, it is obvious that a written description of the article is greatly preferable to a verbal one; but, even with a written explanation, the liability of forming a wrong conception of the shape of the article still exists. The safest, shortest, and most convenient method of describing the form of an article is by means of a properly executed drawing. In such a drawing, every detail of the article is correctly represented, so that all measurements required for its construction can be obtained from the drawing, which, furthermore, shows exactly how the article will appear when completed.

The process of making correct representations of objects by means of drawings is called **orthographic projection** and also **projection drawing.**

2. In general, anything shaped or formed to serve as a model or guide in forming something else is called a **pattern.** In sheet-metal work and boilermaking, the term pattern refers specifically to that outline on a flat sheet which will give an article of the required form and size when the sheet is properly bent.

If the same article is to be produced repeatedly, the pattern may be drawn on a thin sheet of metal, which is then cut to the outline drawn. This sheet is laid successively on the material from which each like part of each article is to be made, and its outline is marked off; when a pattern is thus used it is called a **templet.** The object of using a templet is to save the time required to lay out a pattern on each sheet.

WORKING DRAWINGS

3. In general, before a pattern of any sheet-metal article can be produced, a projection drawing of the article must be made, enough views being given to show clearly the shape and size of the article. Since this drawing is used by the workman, it is called a **working drawing.** It may show the article full size, when it is called a **full-size drawing,** or it may be made to such a scale that the drawing is very much smaller than the article itself, when it is spoken of as a drawing made to a **reduced scale.** In the case of very simple articles, working drawings are sometimes omitted.

PLANES AND LINES OF PROJECTION

PRINCIPAL PLANES OF PROJECTION

4. The most familiar representations of objects are those used merely for illustrative purposes and known as **perspective drawings.** They are of comparatively little value to the artisan or mechanic, because they can rarely be made to serve as working drawings; although they may give perfectly correct ideas of the form, proportions, and general appearance of the object, they are not drawn to a scale in the same manner as are projection drawings. In a perspective drawing, the purpose of which is to show the object as it actually appears to the eye, some lines that are parallel on the object are represented by lines that converge, equal lines are represented by lines of unequal length, right angles on the object are represented by angles that are obtuse or acute; so that, in general, to obtain working measurements therefrom is an operation both complicated and indirect. To make this clear, a perspective drawing of a prism with parallel ends and parallel edges is presented in Fig. 1. It will be observed that the drawing represents the prism as it appears to the eye; thus, the edge *A B* seems to be parallel to the edges *C D* and *E F*. Yet, if a pair of dividers is used for comparing the lengths *A C* with *B D*, *A E* with *B F* and *E C* with *F D*, it will be found that they are not equal and hence the edges of the prism are not parallel in the illustration, although they look to be so. The illustration has been drawn to show a prism having ends that form equilateral triangles, that is, triangles in which all angles are equal; on comparing the angles *E A C*, *A C E*, and *C E A*, it will be found that they are not equal in the illustration, although they appear to be so, and are parallel in reality on the prism.

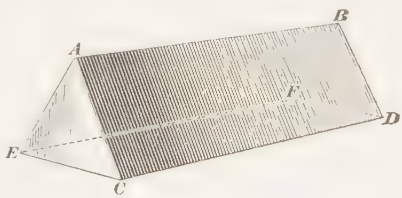


FIG. 1

Fig. 2

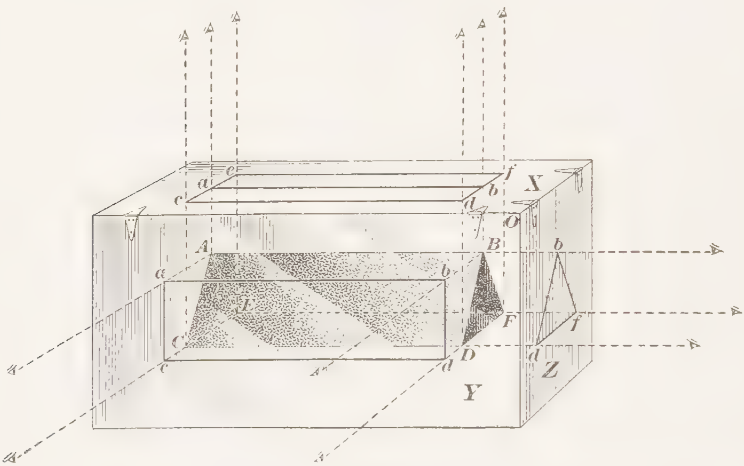


Fig. 3

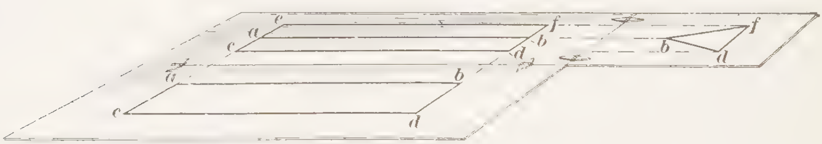


Fig. 4

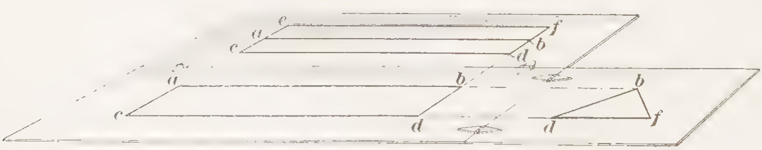


Fig. 5

In Fig. 2 is presented an orthographic projection drawing of the prism illustrated in Fig. 1, three views being given. In this drawing, the edge *a b* is actually drawn parallel to the edges *c d* and *e f*, and the angles *b d f*, *d f b*, and *f b d* are equal, since the edges *b d*, *d f*, and *f b* are of equal length. Consequently, if the drawing is made to some indicated scale, the actual length of each edge can be measured directly therefrom, and the angles can be determined by using a protractor.

5. To a person unconversant with the principles of projection drawing, Fig. 2, which is really an undimensioned working drawing of the prism, will probably be meaningless; to one familiar with these principles, the lines of each view, considered in relation to those of the other views, have a definite and unmistakable meaning.

In the method of projection drawing in almost universal use in the United States of America, the object to be drawn is supposed to lie within transparent planes perpendicular, that is, at right angles, to one another and infinite in extent; these are called the **principal planes of projection,** and sometimes **principal reference planes.** Suppose that three of these imaginary planes are represented by the thin sheets of glass *X*, *Y*, and *Z* in Fig. 3, perpendicular to one another, and suppose that the sheets *Y* and *Z* are each hinged to *X* so they can be swung upwards level with *X*. The plane *X* is always supposed to be horizontal, and hence is called the **horizontal plane;** the plane *Y* is vertical and in front of the object, and is called the **front vertical plane;** the plane *Z* is also vertical and to one side of the object, and is variously called the **end, side,** or **profile plane.** For brevity, these principal planes are referred to as the *horizontal*, the *front*, and the *end* or *side* or *profile plane*.

Assume that the prism *A B C D E F* of Fig. 1 is placed within the reference planes *X*, *Y*, and *Z* of Fig. 3, which may be likened to three sides of a transparent box. In imagination, bring the eye into a position vertically above the corner *A* of the prism; the imaginary straight line from the eye to the

corner A is called a **line of sight,** and that part of the line of sight from the corner A to the point of intersection a of the line of sight with the horizontal plane X is called a **projector.** The intersection of a projector with a given reference plane is the **projection of the point** from which the projector is drawn. By imagining the eye to be placed successively over the different corners of the prism, the projections a, b, c, d, e, and f of the corners are given on the horizontal plane X. Joining these points of projection by lines gives the outline $c\ a\ e\ f\ b\ d$, which is the **horizontal projection** of the prism. If the projection of the corners of the prism is repeated on the planes Y and Z, the lines of sight and hence the projectors being perpendicular to these planes, the **front projection** $a\ b\ d\ c$ of the prism is given on the front plane Y and the **side projection** $b\ d\ f$ on the side plane Z.

6. The line of intersection of the horizontal plane with the front plane is called the **horizontal axis;** the line of intersection of the horizontal plane with the side plane is the **side axis;** the line of intersection of the front plane with the side plane is the **vertical axis.** The point O, Fig. 3, where the three axes intersect, is called the **origin** of the axes.

7. On an actual orthographic projection drawing, the different projections of an object are, of necessity, shown on a single plane. Imagine the front plane Y, Fig. 3, to be turned upwards on the horizontal axis, and the side plane Z to be turned upwards on the side axis until they are level with the horizontal plane, or as shown in Fig. 4. Then, the horizontal projection of the prism, the front projection, and the side projection will all be in one plane, the same as that of the drawing shown in Fig. 2.

The projection drawn on the horizontal plane is called either the **plan view,** the **horizontal view,** the **horizontal projection,** or the **top view;** the projection on the front plane is the **front view, front projection,** or **front elevation;** the projection on the side plane is the **side view, side projection, end view,** or **side elevation.**

8. The different views are often arranged on the drawing as shown in Fig. 4; frequently, however, it becomes necessary or is advisable to have the side view at the right of the front view. To place the side view thus, the side plane is imagined to be turned on the vertical axis until it is level with the front plane, and the front plane and side plane are then turned on the horizontal axis until they are level with the horizontal plane, as indicated in Fig. 5.

AUXILIARY PLANES OF PROJECTION

9. When a surface of an object is parallel to a reference plane, the projection of that surface on the reference plane is called a **full view;** all lines forming the outline of that surface are shown in their true length in a full view. All lines parallel to a reference plane, when projected thereon, are also shown in their true length. Lines making an angle with a reference plane, when projected thereon, are shown shorter than they really are; such a line, when projected, is said to be **foreshortened.**

Referring back to Fig. 3, the prism is so placed within the reference planes that the edges $A B$, $C D$, and $E F$ are parallel to the horizontal and front planes, and the edges $A C$, $B D$, $C E$, $D F$, $A E$, and $B F$, which define the end surfaces of the prism, are in planes parallel to the side plane, and hence are parallel to the side plane. Then, on the front plane Y the projected lines $a b$ and $c d$ are true projections of the edges $A B$ and $C D$; the edges $a c$ and $b d$ are not of the same length, however, as the edges $A C$ and $B D$, but are foreshortened. The true length of the edges $A B$, $C D$, and $E F$ is also given on the horizontal plane X by the projected lines $a b$, $c d$, and $e f$, and the edges $a c$, $a e$, $b d$, and $b f$ show foreshortened, as they make an angle with that plane. The true length of the edges $A C$ or $B D$, $A E$ or $B F$, and $C E$ or $D F$ is given by the projected lines $b d$, $b f$, and $d f$ on the side plane Z, since they are parallel to that plane.

10. In practice, it often happens that objects have surfaces not parallel to the principal reference planes, and that

full views of such surfaces are required for the purpose of construction. In such a case, it is customary to make use

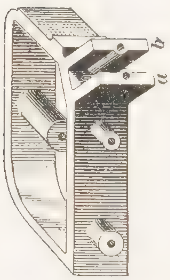


Fig. 6

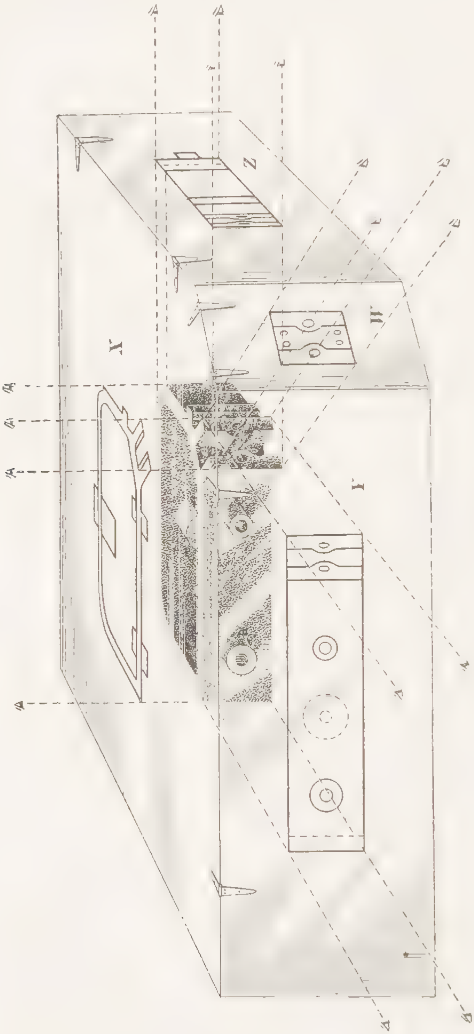


Fig. 7

of an imaginary reference plane parallel to the surface to be projected; this plane is called an **auxiliary reference plane,** or **auxiliary plane of projection.**

Suppose it is required to make a projection drawing for a casting having the form shown in Fig. 6. This casting, as shown in Fig. 7, can, in imagination, be placed inside of the three principal planes *X*, *Y*, and *Z* so that most of its edges can be projected in their true lengths. In order to obtain a full view of the two lugs *a*, *b*, Fig. 6, projecting from one corner of the casting, the auxiliary reference plane *W*,

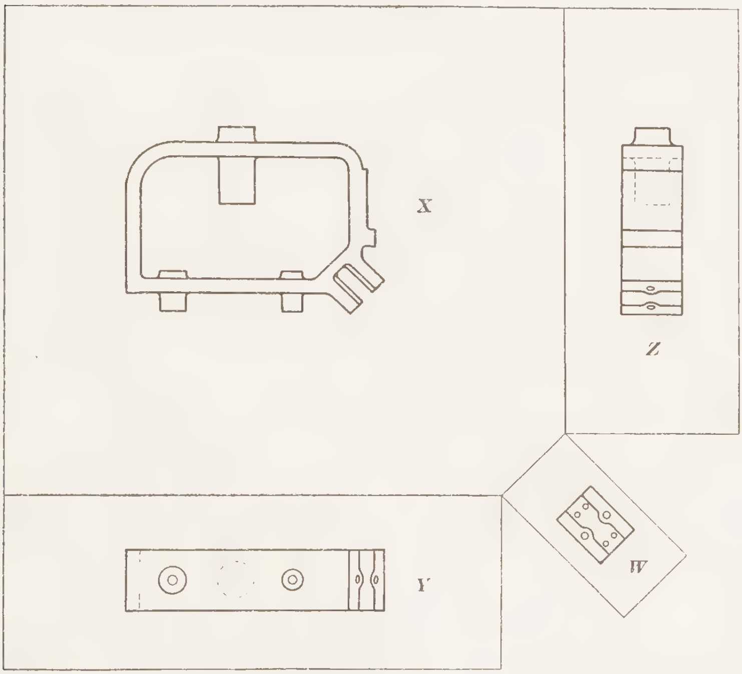


FIG. 8

Fig. 7, is in imagination placed parallel to the end surface of the two lugs, and the lugs are projected thereon, as shown. It will be noticed that the auxiliary reference plane *W* intersects the three principal reference planes; the lines of intersection of any auxiliary reference plane with the three principal reference planes are called the **traces** of the auxiliary plane, and on a drawing they define the exact position of the auxiliary plane. Specifically, the intersection of an auxiliary

plane with the horizontal plane is called its **horizontal trace;** the intersection with the front plane is the **front trace,** and the intersection with the side plane is the **side trace** of the given auxiliary reference plane. The intersections of the three traces are always in the horizontal axis, vertical axis, and side axis of the three principal reference planes. In the case of an auxiliary plane that is perpendicular to one and inclined to two of the principal planes, as the plane *W* in Fig. 7, the traces intersect on but two of the axes.

If, now, the front plane *Y* and the side plane *Z* are turned upwards on the horizontal axis, and side axis, and if the auxiliary plane *W* is turned upwards on its horizontal trace, until the three planes are level with the horizontal plane *X*, the four projected views, as shown in Fig. 8, are brought into a single plane, which is that on which the drawing is made. In the finished working drawing, the different axes of the principal planes and traces of the auxiliary planes are rarely shown, although they are sometimes drawn in pencil to permit the projection of the different views and afterwards erased.

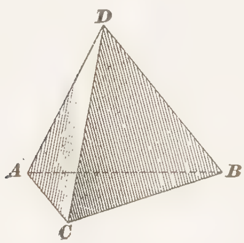


Fig. 9

11. Auxiliary reference planes are not necessarily perpendicular to one of the principal planes, since, in many cases, the surface of which a full view is desired is not perpendicular to a principal plane of projection. In Fig. 9 is shown a regular triangular pyramid in which the base *A B C* is equilateral; the three sides *A C D*, *A B D*, and *C B D* are equal and their side edges form isoscèles triangles with the base edges. This solid is of such a shape that only one of its surfaces can be parallel to one of the principal reference planes, and consequently the projections of the other surfaces on the two other principal reference planes will be foreshortened. If it be required to construct the triangular pyramid, say of cardboard, it is necessary to know the correct length of one edge of the base and one edge of a side, as the edges *A C* and

$C\,D$, for instance. Suppose that the pyramid is placed inside of the three principal reference planes X, Y, and Z, Fig. 10, so that its base $A\,B\,C$ is parallel to the horizontal plane, and the edge $B\,C$ is not parallel to the side plane. Then, the projections $a\,b$, $b\,c$, and $c\,a$ of the edges $A\,B$, $B\,C$, and $C\,A$ will show in their true lengths in the horizontal plane X. Since the sides of the pyramid are equal, a full view of one side is sufficient. This is obtained by making use of an

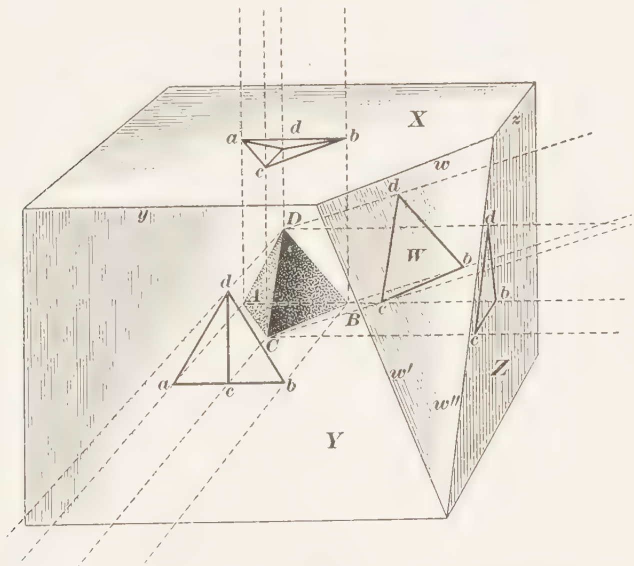


Fig. 10

auxiliary plane W parallel to the side $B\,C\,D$ and projecting into the auxiliary plane the edges $B\,C$, $C\,D$, and $D\,B$.

To bring the four projected views into a single horizontal plane, which, in practice, is the plane of the drawing, the front and side planes are turned on their axes y and z, and the auxiliary plane on one of its traces, say the horizontal trace w, until they are level with the horizontal plane, or as shown in Fig. 11.

12. It often happens that the external appearance of an object is simplicity itself compared with its internal arrangement, and as all sorts of hollow objects, which cannot

be explained by external views alone, must be manufactured, means of showing this internal construction are neces-

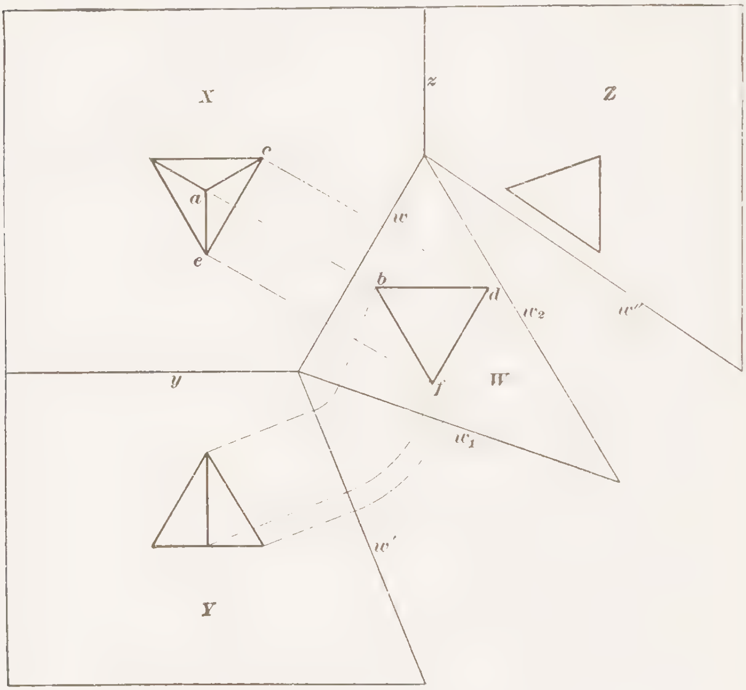


Fig. 11

sary. The required result is accomplished by passing an imaginary plane through the object, cutting it in two, as it were, whence this auxiliary reference plane derives the name of **cutting plane.** For instance, assume that it is required to show the internal construction of the object pictured in

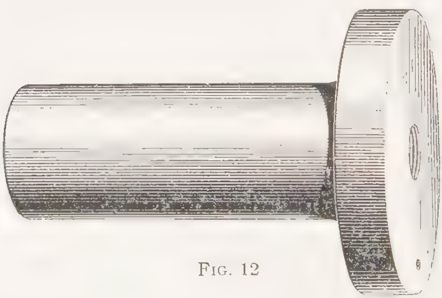


Fig. 12

Fig. 12; it will be obvious that the external view gives no idea as to the internal construction.

To obtain a view of the interior, the object is placed inside of the principal reference planes, as shown in Fig. 13, using, in this case, the horizontal plane X and the side plane Z, although the horizontal and front planes may be used just as well. The object is now cut in two by the imaginary cutting plane $x\,y$ and the part next to the side plane is removed. The edges on the cutting plane, which, in this case, is taken

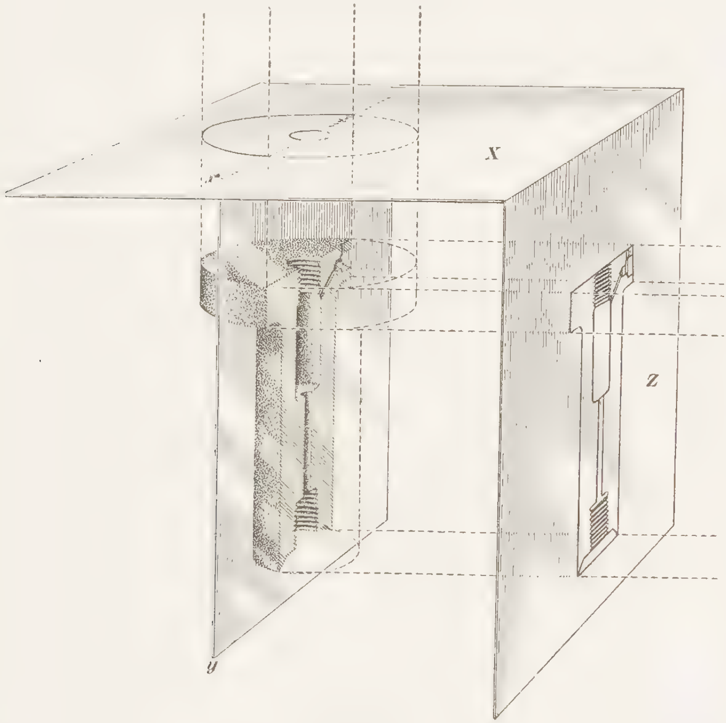


Fig. 13

parallel to the side plane Z, are now projected on the side plane, as shown. The projected view on this plane is called a **sectional view,** or **section** for brevity. If, now, the side plane Z, Fig. 13, is turned upwards on the side axis until it is level with the horizontal plane X, the plan and section will be in one plane, which is that of the drawing, and will appear as shown in Fig. 14.

13. A cutting plane need not necessarily be parallel to one of the principal planes of reference; if it makes an angle with them, the sectional view, if a full view is required, is projected on an auxiliary reference plane parallel to the

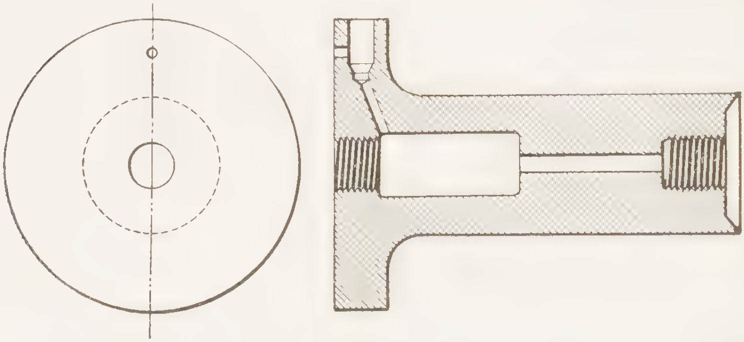


FIG. 14

cutting plane, which auxiliary reference plane is then turned to the level of the horizontal plane. Generally speaking, if circumstances permit, it is advisable to have the cutting plane parallel to a principal plane.

PROJECTION LINES ON DRAWINGS

14. In making an actual projection drawing, where all views are necessarily drawn on a single plane, as that of the drawing board, for instance, a projector, which is that part of a line of sight extending from a given point of the object to be drawn to a reference plane, can be made use of only in an indirect manner. Keeping in mind that a projector is always at right angles to the reference plane to which it leads, consider Fig. 15 (*a*), where the given point *A* is definitively located in space in reference to the three principal planes *X*, *Y*, and *Z* by the projectors *A x*, *A y*, and *A z*. Now imagine that the projector *A x* is itself projected on the front plane *Y* as shown by the straight line *y y*′, and also on the side plane *Z* as shown by the straight line *z z*′. Furthermore, imagine that the projectors *A y* and *A z* are projected into the horizontal plane *X*, as shown by *x y*′ and *x z*′. Then, the projections

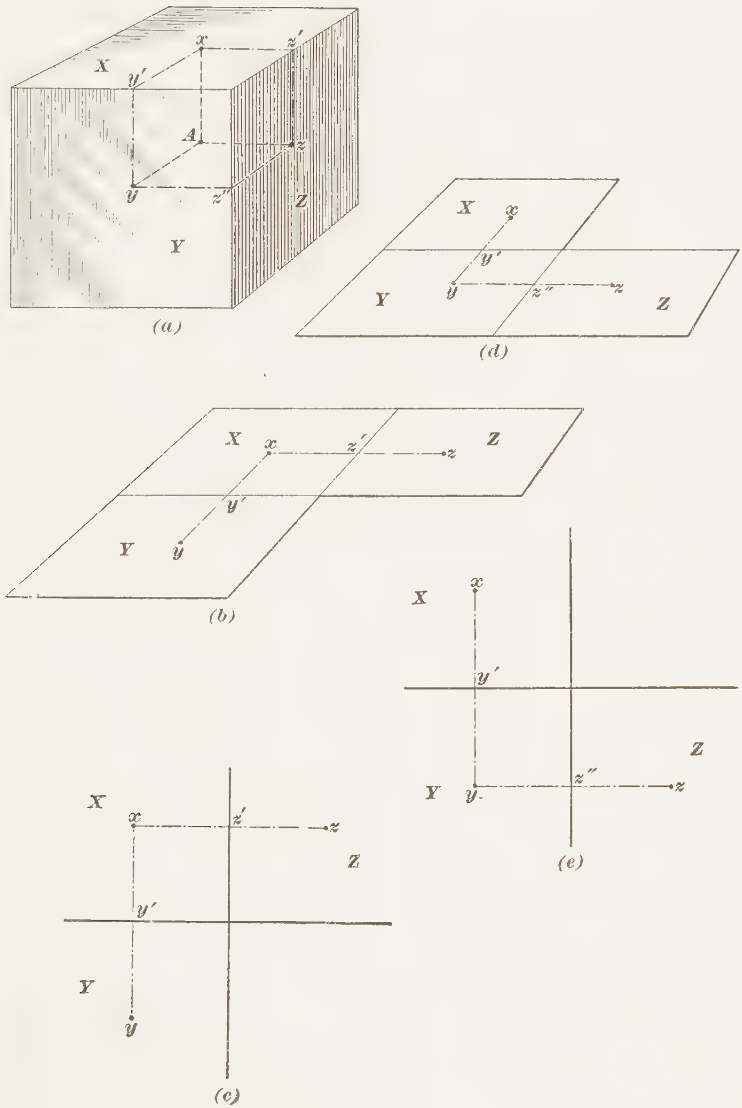


FIG. 15

$x\,y'$ and $y'\,y$ intersect on the horizontal axis and are perpendicular to it; the projections $x\,z'$ and $z'\,z$ intersect on the side axis, to which they are perpendicular.

If the front plane and the side plane are now turned on the horizontal and side axes until they are level with the horizontal plane, as shown in Fig. 15 (*b*), the projections of the projectors are represented by the two straight lines $x\,y'\,y$ and $x\,z'\,z$; these projections of projectors are the lines used in making a projection drawing, and to distinguish them from the imaginary projectors they are called **projection lines,** and often **construction lines.** From what has been said, it will be obvious that a projection line crossing one of the axes of the three principal planes is a representation of two projectors; furthermore, projection lines are always perpendicular to the axes of the principal reference planes, as shown in Fig. 15 (*c*), which illustrates in orthographic projection what Fig. 15 (*b*) shows in perspective.

15. In case a point in space is projected on an auxiliary reference plane, as was shown in Fig. 10, the two projections of the projector, when the auxiliary plane is turned to the level of the horizontal plane on the trace crossed by the projections, will form a single straight projection line perpendicular to the trace. Thus, in Fig. 11, projection lines, as $a\,b$, $c\,d$, and $e\,f$, passing into the auxiliary plane W are perpendicular to the trace w.

16. Returning again to Fig. 15, suppose that it is desirable to have the end view to the right of the front view. In imagination, the projector $A\,z$, Fig. 15 (*a*), is projected into the front plane Y as shown by the straight line $y\,z''$, and the projector $A\,y$ is projected into the side plane Z as shown by the straight line $z\,z''$. To bring the three planes into the plane of the drawing, the side plane is turned on the vertical axis and the front plane on the horizontal axis until both are level with the horizontal plane, which position is shown in perspective in Fig. 15 (*d*), and in Fig. 15 (*e*) as it would appear on a projection drawing.

17. It is not necessary that the side plane shall be located at the right of the front plane, or of the horizontal plane; it may be and often is taken at the left of the other planes. When a bottom view of an object is desired, a plane parallel to the horizontal plane is imagined to be beneath the object; when a rear view is desired, a plane parallel to the front plane is in imagination placed between the observer and the rear of the object.

18. It is an axiom of geometry that the exact location of a plane is given by two parallel lines, or by two straight lines that can or do intersect, or by one straight line and one point, or by three points not in the same straight line. Since, in Fig. 15 (*a*), the projectors and their projections are parallel, each projector and its projection locates an auxiliary plane whose one trace is the projection of the projector. Thus, the auxiliary plane $A\ z\ z''\ y$ has as its traces the projections $y\ z''$ and $z''\ z$; the auxiliary plane $A\ z\ z'\ x$ has as its traces the projections $x\ z'$ and $z'\ z$; the auxiliary plane $A\ x\ y'\ y$ has as its traces the projections $x\ y'$ and $y'\ y$. In other words, projections of projectors, and hence projection lines on drawings, may be conceived to be traces of auxiliary planes. The viewing of projection lines as traces of planes often proves very useful in solving problems that require the use of an auxiliary plane oblique to the three principal planes.

REVOLVED AXES AND TRACES

19. Referring to Fig. 15 (*a*), assume that the planes X, Y, and Z are made of very thin glass. Then, the vertical axis may be considered to be the junction of one edge of the front plane with the front edge of the side plane, and the side axis as the junction of one edge of the horizontal plane with the top edge of the side plane. If the front and side planes are now turned to the level of the horizontal plane, as indicated in Fig. 15 (*b*), the front edge of the side plane becomes a continuation of the horizontal axis; this position of the front edge is called the **revolved vertical axis.** If the front

and side planes are turned into the position shown in Fig. 15 (*d*), the top edge of the side plane becomes a continuation of the horizontal axis and is called the **revolved side axis.** From the foregoing, it will be apparent that the same straight line forming a continuation of the horizontal axis beyond the origin of the axes is either the revolved vertical axis or the revolved side axis, depending on the position into which the side plane is revolved.

20. Referring to Fig. 10, the front trace w' may be conceived to be the junction of an edge of the front plane with the front edge of the auxiliary plane W. Likewise, the side trace w'' may be considered as a junction of the side edge of the auxiliary plane W with the side plane Z. When the front plane, auxiliary plane, and side plane are turned to the level of the horizontal plane, as indicated in Fig. 11, the front edge of the auxiliary plane W is at w_1, and the side edge at w_2. The edges w_1 and w_2 are called the **revolved front trace** and the **revolved side trace,** respectively. The edge w'' is the side trace.

Since revolved axes and traces are two important factors in the solution of problems arising in orthographic projection, the exact manner in which these factors are obtained, and what they represent, must not only be clearly and fully understood, but also firmly fixed in the mind.

SUMMARY OF TECHNICAL TERMS

21. In orthographic projection, the object is imagined to be within a transparent rectangular box, the top and bottom of which are the top horizontal and bottom horizontal planes; the right and left sides of the box are the right and left side planes; the front and back of the box are the front and rear planes. The transparent box has no fixed size; the only condition is that it must be larger than the object to be drawn.

The intersections of the horizontal planes with either the front or the rear planes are the horizontal axes; the intersections of the side planes with the horizontal planes are the

side axes; the intersections of the front or rear planes with the side planes are the vertical axes.

In practice, the bottom plane, rear plane, and one side plane are seldom used; the object to be drawn is, in imagination, turned so that it can be drawn on the top horizontal plane, one side plane, and the front plane. This limits the axis used in practice to one horizontal axis, one vertical axis, and one side axis.

Intersections of auxiliary planes with the principal planes are *traces:* intersections of the principal planes are *axes.*

Projections of projectors are *projection lines* and are always perpendicular to axes and traces; when convenient, projection lines may be considered as traces of auxiliary planes. A projection line crossing an axis or trace is the projection of two projectors.

Revolved axes and traces may be conceived to be edges of planes that have been turned to the level of the horizontal plane; revolved axes are continuations of axes beyond their origin; traces and revolved traces always intersect on the axes.

Auxiliary planes may be parallel and perpendicular to the principal planes; they may be perpendicular to one principal plane and oblique to two principal planes, or they may be oblique to the three principal planes.

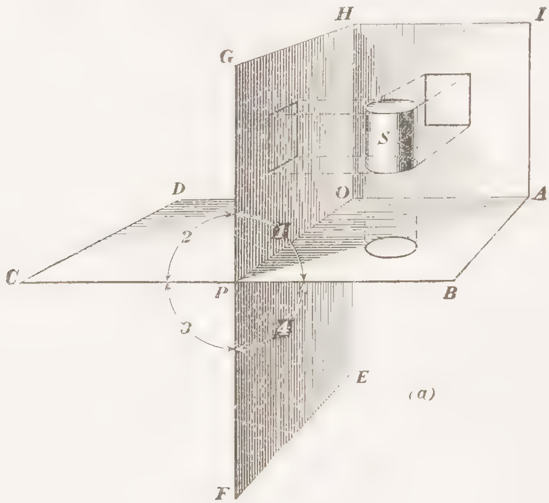
THIRD- AND FIRST-ANGLE PROJECTION

22. In projection drawing, two methods of projection are used; they are termed *third-angle projection* and *first-angle projection.* The method first named is the one used almost exclusively in the United States of America, and is the one here treated; the second method is in common use in Europe.

Referring to Fig. 16, let $A\ B\ C\ D$ be a horizontal plane and $E\ F\ G\ H$ a vertical plane intersecting it on the axis $P\ O$. There are formed four right angles; $G\ P\ B$ is called the **first angle;** $G\ P\ C$, the **second angle;** $C\ P\ F$, the **third angle;** and $F\ P\ B$, the **fourth angle.**

In Fig. 16 (a), a cylinder S is placed within the vertical plane $P\ O\ H\ G$ and the horizontal plane $P\ O\ A\ B$, which are

assumed to be opaque. The object to be drawn is assumed to be transparent. The lines of sight are projected from the



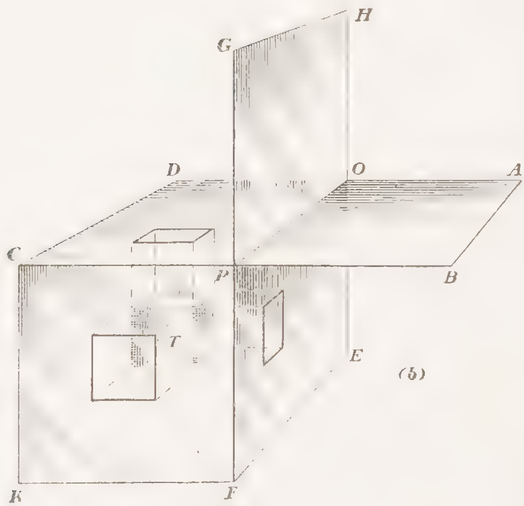


FIG. 16

eye of the observer to the plane of projection, *through the object*. Since the object is within planes forming the first

angle, this method of projection drawing is called **first-angle projection.**

In Fig. 16 (*b*), the object, in this case a cube *T*, is placed inside of the planes *P O D C* and *F P O E* that form the third angle; the planes are assumed to be transparent and the lines of sight pass from the eye of the observer *through the plane* to the object. Since the object is placed in the third angle, this method of projection drawing is termed **third-angle projection,** and is the one explained here.

The same results are obtained by the use of either method of projection, except in the relative positions of the different views on a drawing. In third-angle projection, a top view shows above a front view, and a right-hand side view shows at the right of the front or the top view, as in Fig. 15 (*c*) and (*e*); in first-angle projection a top view shows below the front view, and a right-hand side view shows at the left of the front or the top view.

PROJECTION OF POINTS

PROJECTING A POINT ON PRINCIPAL PLANES

23. The positions of two or more points locate lines, and the location and length of lines locate and define surfaces, which, in turn, bound solids. Consequently, the projection of solids ultimately resolves itself into the projection of points. Hence, if the principles underlying the projection of a point on any principal or auxiliary plane of projection are thoroughly understood, little trouble will be experienced in projecting lines, and hence surfaces and solids, on any plane of projection.

24. The simplest problem in projection drawing and the one that occurs the most frequently is to find the projection of a point on one of the three principal planes when its projection on the two other planes is known. In making an actual drawing, the solution is as follows: The paper on

which the drawing is to be made having been fastened to the drawing board, a horizontal line of any convenient length, as $a\,b$ in Fig. 17 (*a*), is drawn in any convenient location. Similarly, the vertical line $c\,d$ is drawn perpendicular to $a\,b$; its intersection e with the line $a\,b$ is the origin of the axes. The part $e\,d$ of the line $c\,d$ represents the side axis and the part $e\,c$ the vertical axis. If the side plane is at the right, the part $a\,e$ of the horizontal line $a\,b$ represents the horizontal axis; the part $e\,b$ is the revolved vertical axis $e\,c$ when the side plane is alongside of the horizontal plane, as shown in Fig. 15 (*b*), and the revolved side axis when the side plane is alongside of the front plane, as shown in Fig. 15 (*d*).

The dot A on the horizontal plane and the dot A' on the front plane are the two given projections of the point; from

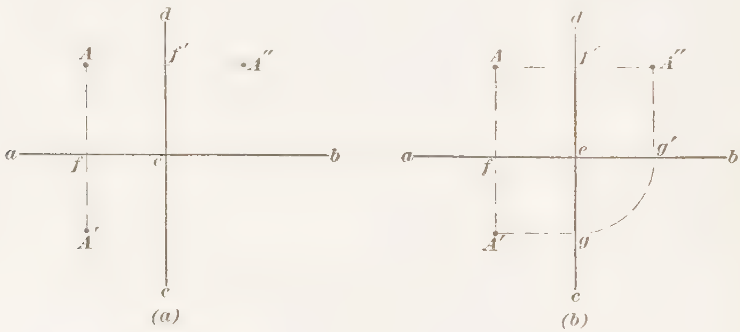


FIG. 17

what has been previously said, it will be apparent that the projection line $A\,A'$ is perpendicular to the horizontal axis $a\,e$. The part $A\,f$ of the projection line gives the exact distance the given point is from the front plane, and the part $f\,A'$ shows the distance the given point is below the horizontal plane. To find the projection of the given point on the side plane, a projection line is drawn through the projection A perpendicular to the side axis, or parallel to the horizontal axis, which is the same thing, and extending some distance into the side plane. Obviously, the projection of the given point on the side plane must be the same distance below the horizontal plane that it is on the front plane; consequently,

if the distance $f\,A'$ is measured and laid off from f' on the projection line extending into the side plane, the projection A'' of the given point is located on the side plane.

25. Instead of transferring to the side plane the distance by measurement that the given point is located below the horizontal plane, the distance may be determined graphically in the manner shown in Fig. 17 (*b*). Through the projection A' of the point, a projection line is drawn to the vertical axis $e\,c$, intersecting it at g. Since this projection line is perpendicular to the vertical axis, it is parallel to the horizontal axis, and hence $e\,g$ is equal to $f\,A'$. With the origin e of the axes as a center and the distance $e\,g$ as a radius, an arc is now struck, intersecting the revolved vertical axis $e\,b$ in g'. At the point of intersection g' is now erected a perpendicular of sufficient length to intersect the projection line drawn through the point A into the side plane; the point of intersection A'' is the projection of the given point on the side plane. The distances $f\,A'$ and $f'\,A''$ must be equal, because $f\,A' = e\,g$, $e\,g = e\,g'$, and since the perpendicular erected at g' is parallel to the side axis, $e\,g' = f'\,A''$.

26. The method of finding the third projection of a point on a principal plane when its projection on the two other principal planes is known, is the same in principle, no matter on what two principal planes the projection of the point is given, and no matter whether the side plane is alongside of the horizontal plane or of the front plane. Thus, in Fig. 18, the projections A and A' of the point are given on the horizontal plane and on the side plane, the latter in this case being alongside of the front plane, on which the projection is to be found. Through A draw a perpendicular to the vertical axis $e\,c$ and extending into the front plane; through A', draw a perpendicular to the horizontal axis $a\,e$ and also extending into the front plane. The intersection A'' of the two projection lines is the projection of the given point on the front plane.

When the two given projections of a point are not on adjacent planes, that is, when the two projections cannot be

joined by a single straight projection line, as in Fig. 18, care must be exercised to see that the given projections are correctly located on the drawing in reference to the axes. Thus, in Fig. 18, the distance $f\,A$ must be equal to $f'\,A'$, since both of these distances represent the distance between the front plane and the point whose projections are given.

Fig. 18

27. Suppose that A' and A'', Fig. 18, are the given projections of the point. To find the projection on the side plane, draw a perpendicular from A'' to the vertical axis, or what is the same thing, draw a projection line parallel to the horizontal axis $a\,e$ and extending sufficiently far into the side plane. Make $f\,A$ equal to $f'\,A'$, either by measurement or by using the method shown in Fig. 17 (b); A will then be the required projection.

28. Since the different axes serve as bases from which measurements are made, they are often called **base lines,** and also **ground lines.**

PROJECTING A POINT ON AUXILIARY PLANES

29. In projecting a point on an auxiliary plane, its projection on two or three of the principal planes being given, there are two cases that occur, namely: (1) the auxiliary plane is oblique to two principal planes and perpendicular to the third; (2) the auxiliary plane is oblique to all three principal planes. Both cases are readily solved by the use of one or more supplementary planes, each perpendicular both to one principal plane and to the auxiliary plane.

30. In Fig. 19 is shown the first case, the auxiliary plane W being, in this instance, at right angles to the front plane. The projection of the point A on the front plane

and the horizontal plane, and also the traces of the auxiliary plane W, are given.

The solution of the problem depends on the selection of the trace on which the auxiliary plane is turned to bring it to the level of the horizontal plane. Suppose that it is turned on its front trace. Draw the horizontal axis $a\,b$, Fig. 20 (a), and the horizontal trace $b\,c$, which, since in this instance, the auxiliary plane is at right angles to the front plane, is at right angles to the horizontal axis, and draw the front trace $b\,d$. Locate the given projections A' and A'' on the horizontal and front planes. Referring back to Fig. 19, pass, in imagi-

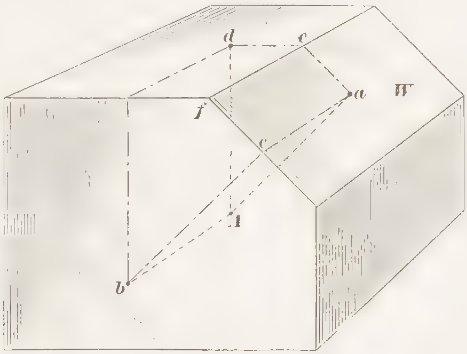


FIG. 19

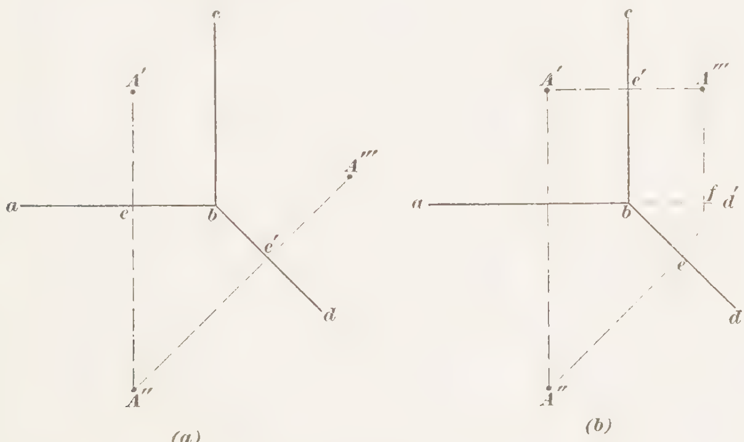


FIG. 20

nation, a supplementary plane through the projection $A\,a$ and $A\,b$. Since the projector $A\,b$ is at right angles to the front plane and $A\,a$ at right angles to the

auxiliary plane, the plane passed through these projectors is also perpendicular to the front and auxiliary planes, and consequently its traces $b\,c$ and $a\,c$ are perpendicular to the front trace of the auxiliary plane W, on which trace the traces $b\,c$ and $a\,c$ intersect. In Fig. 20 (a), from the projection A'' draw a perpendicular to the front trace $b\,d$, extending it into the auxiliary plane. Since $e\,A'$ is the distance the given point is from the front plane, lay off $e'\,A''' = e\,A'$ from the front trace; A''' is the projection of the given point on the auxiliary plane.

If the auxiliary plane is turned around its horizontal trace, the solution of the problem is as shown in Fig. 20 (b). Through the projectors $A\,a$ and $A\,d$, Fig. 19, pass, in imagination, a supplementary plane, which necessarily is perpendicular both to the horizontal plane and the auxiliary plane W. Then, its traces $d\,e$ and $e\,a$ will be perpendicular to, and intersect on, the horizontal trace. Consequently, in Fig. 20 (b), through the projection A', pass a perpendicular to the horizontal trace $b\,c$, extending sufficiently into the auxiliary plane. From A'' draw a perpendicular to the front trace $b\,d$, intersecting this trace at e. The distance the projection of the given point is from the horizontal trace is given by the distance $b\,e$; consequently, by laying off from the horizontal trace $b\,c$ the distance $e'\,A''' = b\,e$, the required projection A''' is found. The reason why $e'\,A''' = b\,e$ can be readily seen by referring back to Fig. 19. Since the auxiliary plane W is perpendicular to the front plane, its front trace is perpendicular to its horizontal trace. The trace $a\,c$ is also perpendicular to the front trace and hence parallel to the horizontal trace. Likewise, the trace $a\,e$ is parallel to the front trace. From this it follows that $e\,a = f\,c$.

Should it be inconvenient to transfer the distance $b\,e$, Fig. 20 (b), by measurement, it can be done graphically by first drawing the revolved front trace $b\,d'$, and then drawing an arc $e\,f$ with b as a center and erecting a perpendicular at the point f on the revolved trace. The intersection A''' of this perpendicular with the projection line drawn across the horizontal trace is the projection of the given point.

31. When the auxiliary plane is perpendicular to one of the principal planes, the revolved trace is found by erecting a perpendicular at the intersection of the traces and on that trace on which the auxiliary plane was turned to the level of the horizontal plane, since, in this case, as a consideration of Fig. 19 will show, the horizontal trace, as well as the side trace, is at right angles to the front trace.

32. The projection of a point on an auxiliary plane oblique to all three principal planes, when the projections of the point on two principal planes and the traces of the auxiliary plane are given, is solved by the use of two supplementary planes. Thus, in Fig. 21 (a), let A be the point in space whose projections A' and A'' on the horizontal and front planes are given. Assume that through the projector $A\,A'''$ are passed two supplementary planes, the one being

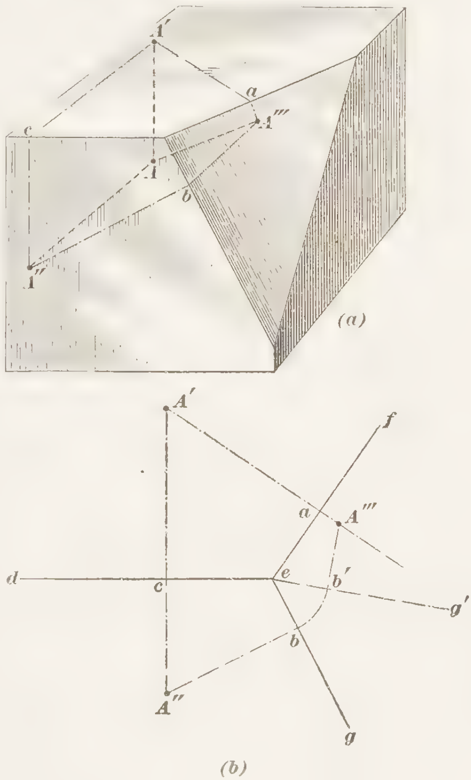


Fig. 21

perpendicular to the horizontal plane and to the auxiliary plane, and the other perpendicular to the front plane and to the auxiliary plane, Then the traces $A'\,a$ and $a\,A'''$ of the supplementary plane $A\,A'\,a\,A'''$ are perpendicular to the horizontal trace; the traces $A''\,b$ and $b\,A'''$ of the supplementary plane $A\,A'''\,b\,A''$ are perpendicular to the front

trace. Obviously, the intersection of the traces $a\,A'''$ and $b\,A'''$ on the auxiliary plane is the projection of the point A on that plane.

Referring now to Fig. 21 (b), draw the front axis or base line $d\,e$, the horizontal trace $e\,f$, and the front trace $e\,g$. Locate the given projections A' and A'' of the point. Assume that the auxiliary plane is turned on its horizontal trace to the level of the horizontal plane. Through A' draw a perpendicular to the horizontal trace $e\,f$ and extending sufficiently into the auxiliary plane; the projection of the point, as a consideration of Fig. 21 (a) will show, lies on this projection line. Next, in the manner explained in Art. **33,** lay off the revolved front trace $e\,g'$, and through the projection A'' draw a perpendicular to the front trace $e\,g$, intersecting this trace at b. With e as a center and a radius $e\,b$, describe an arc intersecting the revolved front trace $e\,g'$ at b'.

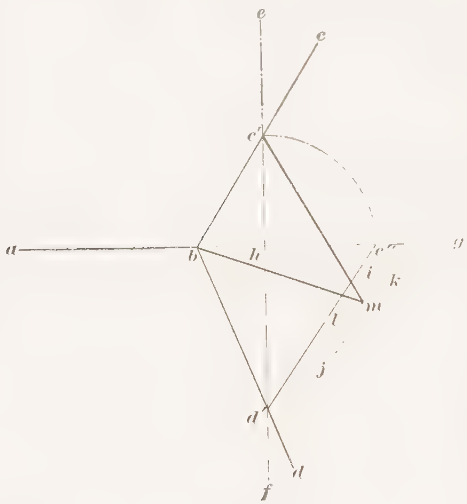


Fig. 22

At b' erect a perpendicular. Its intersection A''' with the perpendicular to the horizontal trace is the required projection.

33. Reference to Fig 21 (a) shows that when an auxiliary plane is oblique to the three principal planes, its traces form a triangle and intersect on the axes. Consequently, the problem of finding the location of a revolved trace resolves itself into erecting a triangle on that trace around which the auxiliary plane was turned to the level of the horizontal plane, the triangle having the three traces for its sides.

When all three traces are given, the triangle can be erected at once; when only two traces are given, the third trace must first be found. Referring to Fig. 22, let $a\,b$ be the horizontal axis, $b\,c$ the horizontal trace, and $b\,d$ the front trace. It is required to find the revolved front trace. Cutting the two given traces, in any convenient location draw a perpendicular $e\,f$ to the horizontal axis, which axis is extended to any convenient distance, say to g. Then, $h\,e$ is a side axis and $h\,f$ a vertical axis, the point h being the origin. The length $b\,c'$ will be that of the horizontal trace and $b\,d'$ that of the front trace, corresponding to the position of the side plane indicated by $e\,f$. Suppose that the side plane has been turned on its vertical axis to bring it alongside of the front plane; $h\,g$ is then the revolved side axis. The end c' of the horizontal trace is the distance $h\,c'$ from the origin h; since the third trace (the side trace in this instance) joins d' and c' before the principal planes are turned to the level of the horizontal plane, it follows that by laying off on the revolved side axis $h\,g$ from the origin h the distance $h\,c'$ the intersection of the side trace with the horizontal trace is given. This may be done by describing an arc with h as a center and $h\,c'$ as a radius, intersecting $h\,g$ at c''. The straight line joining d' and c'' is the side trace corresponding to $b\,c'$ and $b\,d'$.

Suppose that the auxiliary plane is turned on its horizontal trace to the level of the horizontal plane. With b as a center and $b\,d'$ as a radius, describe an arc $i\,j$; with c' as a center and $d'\,c''$ as a radius, describe an arc $k\,l$ intersecting $i\,j$ at m. From b draw a straight line to m; the line $b\,m$ is the revolved front trace. By joining c' and m by a straight line the revolved side trace $c'\,m$ is given.

PRACTICAL PROJECTION
(PART 2)

PROJECTION OF POINTS AND LINES

PROJECTION OF POINTS

GENERAL INSTRUCTIONS

1. A number of exercises, each consisting of several sheets on each of which are one or more problems, are to be drawn by the student and sent to the International Correspondence Schools for correction. The sheets on which all the exercises are to be executed may be about 9 in. × 12 in. outside measurement, and must be 8 in. × 11 in. within the border lines. The different lines on the drawings may be inked in or not, just as the student chooses. Any kind of paper may be used; however, a white paper having a hard, smooth, surface will permit the greatest accuracy, and is recommended.

There will be two or more cases of each problem, of which the solution of the first case will be given quite fully; the other case or cases will be similar to the first, and are to be drawn by the student without further explanation. All problems on each sheet are to be drawn. Having completed the several sheets of an exercise, the number of the exercise, the title of the Paper and its part number, and the number of the sheet are to be written on each sheet at the top and outside of the border line. At the bottom of the sheet and outside of the

border line are to be written the date the drawing was completed by the student, the name of the student, the class letters, and the number. Thus, suppose the drawing is the first sheet of Exercise I, *Practical Projection*, Part 2, and that it was completed on May 14, 1912; suppose the name of the student is John Smith, his class letters are DCA, and his number is 1,280,679. Then, by consulting the reduced copy of Sheet I, Exercise I, on page 34, the form in which the information called for is to be written can be seen. On the back of each sheet of each exercise is to be written the full address of the student. Then mail all the sheets of each exercise, one exercise after the other, to the International Correspondence Schools, Scranton, Pa., for correction. Do not mail single sheets; mail only a complete exercise.

The greatest of care must be exercised to do the work neatly and accurately. Reference letters and dimensions appearing on the reduced copies of the sheets are to be omitted.

IMPORTANT ADVICE

2. Particular attention is called to the fact that orthographic projection is not a matter of rules but of reasoning based upon knowledge of the underlying principles set forth in Part 1; therefore, every endeavor must be made by the student to master thoroughly these principles before any of the exercises are drawn. An attempt to master projection drawing by simply drawing the problems given and hoping to learn the subject by intuition will surely result in failure and involve a waste of time. In order to obtain such a mastery of the subject as will enable him to solve at once any one of the innumerable problems in orthographic projection that may arise in practice, it is absolutely necessary for the student to know the reason for every single step required in the solution of each problem given. He is cautioned against the error of thinking that he can learn the subject by beginning at once to project solids; he should bear in mind that solids are bounded by surfaces defined by lines that, in turn, are located by points. Hence, the student must,

first of all, learn to project points on any principal or auxiliary plane of projection in order to master the subject.

The various problems presented and to be drawn by the student have been carefully selected to lead him from the simplest problem step by step to more difficult ones.

In connection with the statement of the various problems, and also in solutions, certain points and lines are located in reference to the border lines of the sheets on which the solution of the problems are drawn; it should be clearly understood that the location of such points or lines is given only to prevent overlapping of the different views and solutions, and does not form a part of the solution.

Unless specifically stated otherwise, the scale of all dimensions given in connection with problems is full size.

EXERCISE I

3. Projecting Points on Principal Planes.—Exercise I consists of three sheets containing, in all, fourteen problems relating to the location of a point in space in reference to principal planes. Sheet I is to be divided into six equal spaces by lead-pencil lines, and Sheets II and III into four equal spaces.

PROBLEM 1. Sheet I.—One corner of a cube, as shown in Fig. 1, is $1\frac{5}{8}$ inches below the horizontal plane and $1\frac{1}{4}$ inches from the front plane; find its projections on these two planes.

SOLUTION.—Referring to the reduced copy of Sheet I, draw the horizontal axis $a\,b$ in any convenient location, say 2 inches from the upper border line. In any convenient location draw a projection line $c\,d$ perpendicular to the horizontal axis and extending sufficiently into both planes. From the intersection e of $c\,d$ and $a\,b$ lay off $e\,c = 1\frac{5}{8}$ inches and $e\,d = 1\frac{1}{4}$ inches; c and d are the required projections.

If the manner in which the imaginary front and side planes are turned on their axes to bring them level with the horizontal plane is kept in mind, no trouble will be experienced

Exercise I Practical Projection, Part 2 Sheet 1

May 14, 1912 John Smith, DCA 1,280,679

in determining in which direction the measurements are to be laid off from the axes.

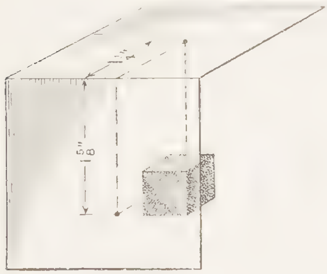


FIG. 1

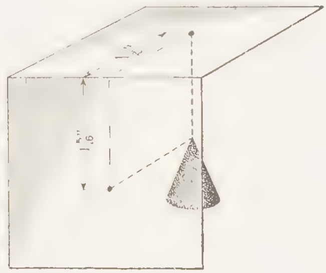


FIG. 2

PROBLEM 2.—The vertex of a cone, as shown in Fig. 2, is $1\frac{5}{16}$ inches from the horizontal plane and $1\frac{1}{2}$ inches from the front plane; find its projections on these two planes.

PROBLEM 3.—One corner of a tetrahedron, as shown in Fig. 3, is 1 inch from the front plane and $1\frac{3}{8}$ inches from the horizontal plane; find its projections on these two planes.

PROBLEM 4.—The vertex of a pyramid is $1\frac{3}{16}$ inches from the side plane and $1\frac{9}{16}$ inches from the front plane, as shown in Fig. 4. The side plane is at the right of the front plane. Find the projections of the vertex on the two planes given.

SOLUTION.—Draw the vertical axis $a\,b$ and draw a projection line $c\,d$ in any convenient location. From the intersection e lay off $e\,c = 1\frac{3}{16}$ inches and $e\,d = 1\frac{9}{16}$ inches. The points c and d are the required projections.

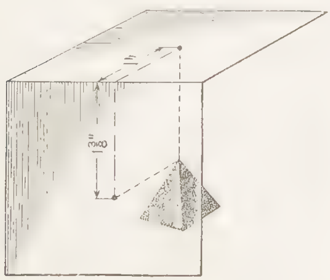


FIG. 3

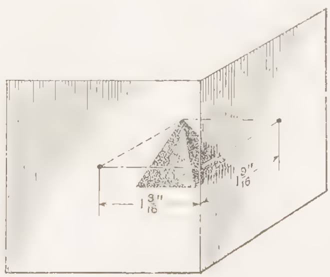


FIG. 4

PROBLEM 5.—Find the front and side projections of one corner of a prism, the corner being $1\frac{1}{2}$ inches from the front and side planes, as shown in Fig. 5. The side plane is at the right of the front plane.

PROBLEM 6.—Find the front and side projections of the vertex of a cone, the vertex being $1\frac{1}{16}$ inches from the front plane and $1\frac{7}{16}$ inches from the side plane, as shown in Fig. 6, the side plane being at the left of the front plane.

4. PROBLEM 7. Sheet II.—One corner of a prism is 1 inch from the front plane and 2 inches from the horizontal plane, as shown in Fig. 7. Find its projections on the front, horizontal, and side planes, the side plane being at the right of the front plane.

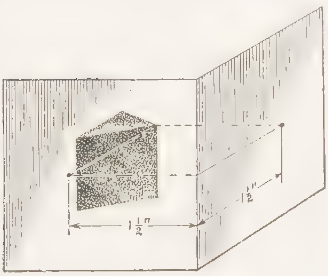


FIG. 5

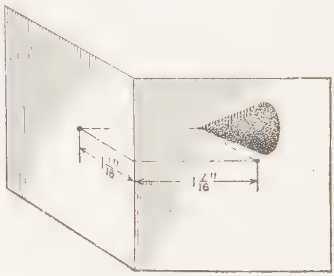
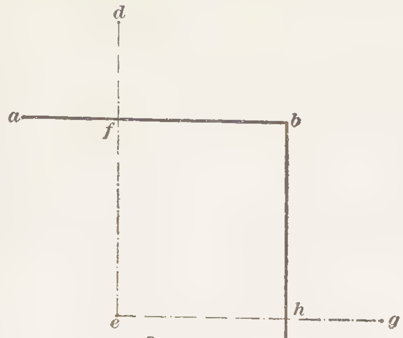


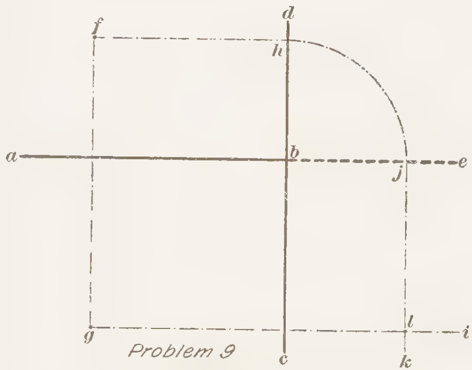
FIG. 6

SOLUTION.—Referring to the reduced copy of Sheet II, draw the horizontal axis $a\,b$ and the vertical axis $b\,c$ in any convenient location, say $1\frac{1}{2}$ inches from the upper border line and 3 inches from the left border line. Since the distance of the point from the side plane is not given, draw at any convenient distance from the vertical axis a projection line $d\,e$ perpendicular to the horizontal axis. From its intersection f lay off $f\,d = 1$ inch, and $f\,e = 2$ inches. The points d and e are the required projections on the horizontal and front planes. To find the projection on the side plane, through e draw a perpendicular $e\,g$ to the vertical axis $b\,c$ and extend it sufficiently far into the side plane; the projection line just drawn is obviously parallel to the horizontal

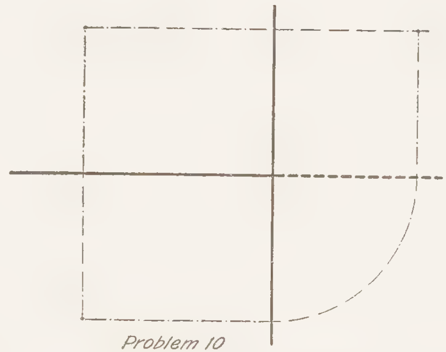


Problem 7

Problem 8



Problem 9



Problem 10

Date

Name of Student, Class Letters, and Number

axis $a\,b$. From the intersection h lay off $h\,g = f\,d = 1$ inch. The point g is the required projection on the side plane.

Problem 8.—The vertex of a pyramid is $1\frac{1}{4}$ inches from the front plane and $1\frac{3}{4}$ inches from the horizontal plane. Find its projections on the three principal planes, the side plane being at the right of the front plane.

Locate the horizontal axis $1\frac{3}{4}$ inches from the upper border line, and the vertical axis $2\frac{1}{2}$ inches from the right border line.

Problem 9.—A point is $1\frac{1}{4}$ inches from the front plane and $1\frac{3}{4}$ inches from the horizontal plane. The side plane being at the right of the front plane, find the projections on the three planes.

Solution.—Referring to the reduced copy of Sheet II, draw the horizontal axis, or base line $a\,b$, and the vertical

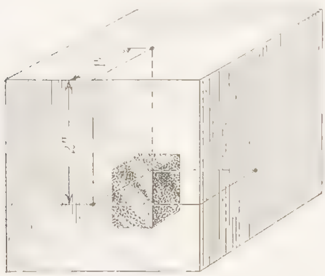


Fig. 7

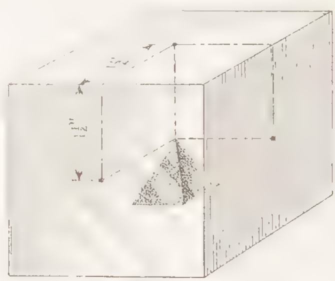
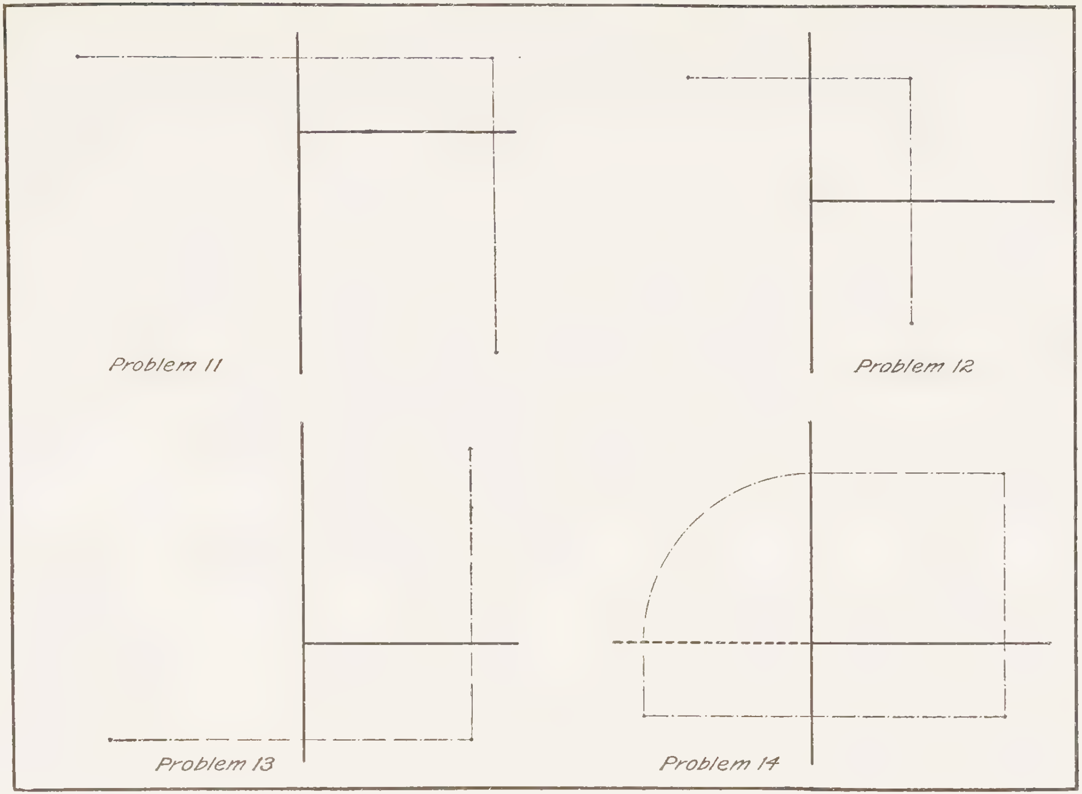


Fig. 8

and side axes or base lines $b\,c$ and $b\,d$, as well as the revolved side axis $b\,e$, in any convenient location, say $2\frac{1}{4}$ inches from the lower border line and 3 inches from the left border line. Since the distance of the point from the side plane is not given, draw a projection line $f\,g$ anywhere to the left of the origin b and by measuring from the horizontal base line $a\,b$ locate the projections f and g on the horizontal and front planes. Through f draw a projection line perpendicular to the side axis, or base line, and hence parallel to the horizontal axis, or base line, and intersecting the side axis, or base line, at h. Through g draw a projection line $g\,i$ extending sufficiently far into the side plane. With the origin b as a center

Exercise I — Practical Projection, Part 2 — Sheet III



Data — Name of Student, Class Letters, and Number

and a radius $b\,h$, describe an arc intersecting the revolved side axis in j. Through the point j draw a line $j\,k$ perpendicular to the revolved side axis, and hence parallel to the vertical axis $b\,c$; the intersection l of the projection lines $j\,k$ and $g\,i$ is the projection of the given point on the side plane.

PROBLEM 10.—The vertex of a pyramid is $1\frac{1}{2}$ inches from the horizontal plane and from the front plane, as shown in Fig. 8. Find its projections on all three planes when the side plane is at the right of the horizontal plane, using the graphical method explained in the solution of Problem 9.

Locate the horizontal axis 2 inches from the lower border line and the vertical axis $2\frac{1}{2}$ inches from the right border line.

5. PROBLEM 11. Sheet III.—The vertex of a cone is $2\frac{1}{4}$ inches below the horizontal plane and $\frac{3}{4}$ inch from the front

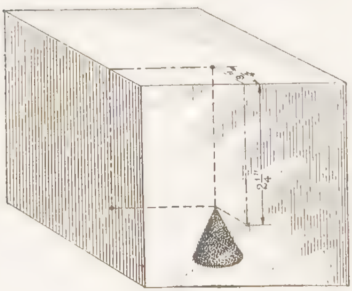


FIG. 9

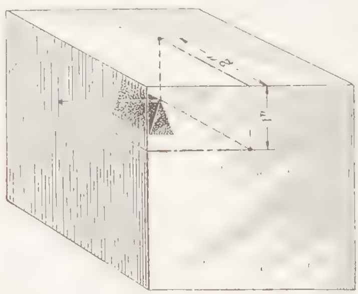


FIG. 10

plane, as shown in Fig. 9. The side plane being at the left of the horizontal plane, find the projections of the vertex on the three planes.

PROBLEM 12.—A point is $1\frac{1}{4}$ inches from both the horizontal and the front plane. The side plane being at the left of the horizontal plane, find the projections of the point on the three planes.

Locate the horizontal axis 2 inches from the upper border line and the vertical axis $2\frac{3}{4}$ inches from the right border line.

PROBLEM 13.—One corner of a wedge is 2 inches from the front plane and 1 inch from the horizontal plane, as shown

in Fig. 10. The side plane being at the left of the front plane, find the three projections of the point.

Locate the horizontal axis $1\frac{1}{2}$ inches from the lower border line and the side axis 3 inches from the left border line.

Problem 14.—A point is $\frac{3}{4}$ inch from the horizontal plane, $1\frac{3}{4}$ inches from the front plane, and 2 inches from the side plane, which is at the left of the front plane. Find the projections of the point on the three planes, using the graphical method explained in the solution of Problem 9.

Locate the horizontal axis $1\frac{1}{2}$ inches from the lower border line and the side axis $2\frac{3}{4}$ inches from the right border line.

EXERCISE II

6. Projecting Points on Auxiliary Planes.—This exercise consists of three sheets; the various problems given relate to the projection of a point on an auxiliary plane.

Problem 15. Sheet I.—One corner of the inclined side of the object shown in Fig. 11 is $1\frac{3}{8}$ inches from the front plane and $1\frac{5}{8}$ inches from the horizontal plane. Find its projection

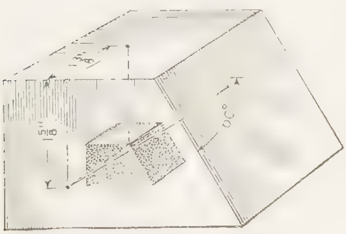


Fig. 11

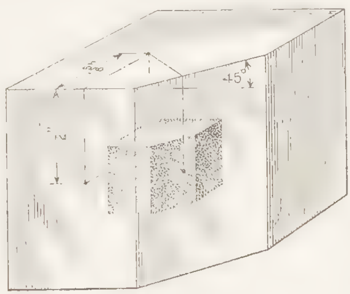


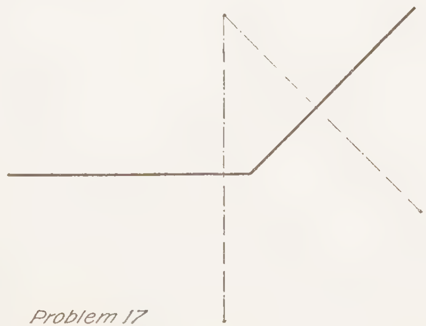
Fig. 12

on an auxiliary plane perpendicular to the front plane and making an angle of 60° with the horizontal plane, in the direction shown, the auxiliary plane having been turned on its front trace and being at the right.

Solution.—Referring to the reduced copy of Sheet I, Exercise II, draw the horizontal axis, or base line *a b*, in

Problem 15

Problem 16



Problem 17

Problem 18

Date Name of Student, Class Letters, and Number

any convenient location, say 2 inches from the upper border line, and let the end *b* be $2\frac{3}{4}$ inches from the left border line; draw the front trace *b c* of the auxiliary plane at an angle of 60° to the horizontal base line, as shown. Since the distance of the point from the auxiliary plane is not given, draw the projection line *d e* in any convenient location perpendicular to the horizontal base line and make $f\,d=1\frac{3}{8}$ inches and $f\,e=1\frac{5}{8}$ inches, thus locating the projections *d* and *e* on the horizontal and the front plane, respectively. Through the projection *e* draw a projection line *e g* perpendicular to the front trace *b c* and make $h\,g=f\,d=1\frac{3}{8}$ inches; *g* is the projection of the given point on the auxiliary plane.

Problem 16.—A point is $1\frac{5}{8}$ inches from the front plane and $1\frac{3}{4}$ inches from the horizontal plane. Find its projection on an auxiliary plane perpendicular to the front plane and making an angle of 45° with the horizontal plane, measured as in Fig. 11, the auxiliary plane having been turned on its front trace and being at the right.

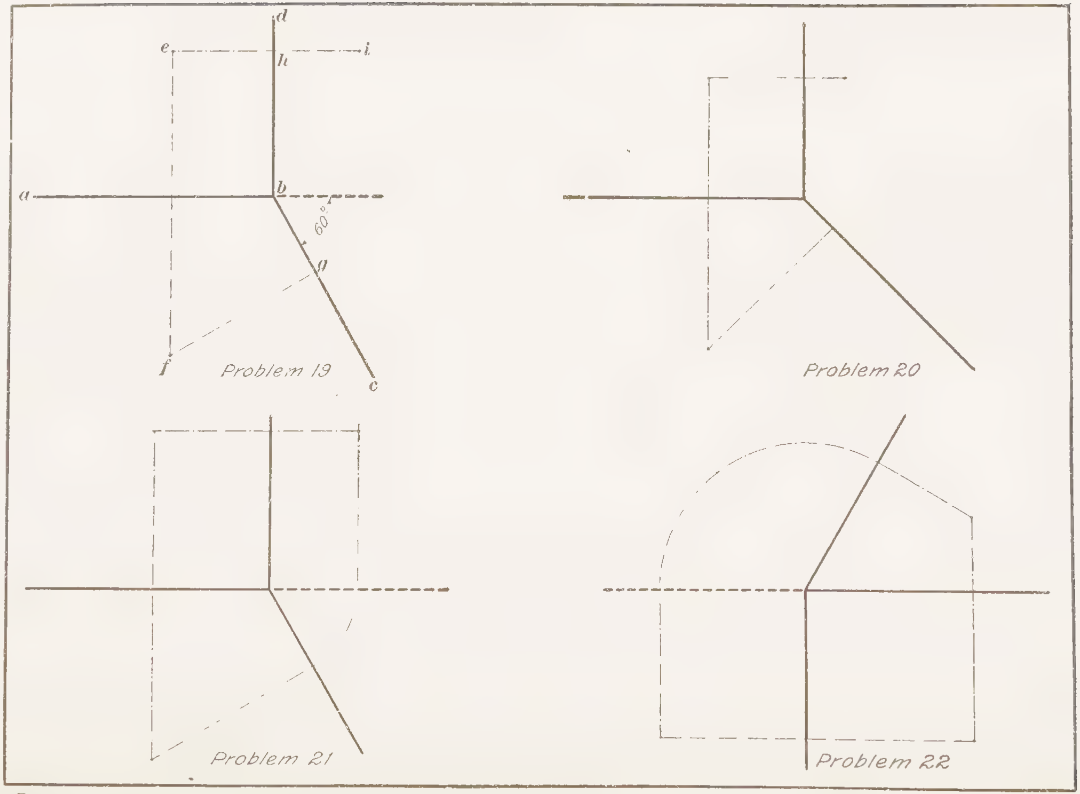
Locate the horizontal axis 2 inches from the upper border line and the intersection of the front trace with the horizontal axis $2\frac{3}{4}$ inches from the right border line.

Problem 17.—One corner of the casting shown in Fig. 12 is $1\frac{5}{8}$ inches from the front plane and $1\frac{1}{2}$ inches from the horizontal plane. Find its projection on an auxiliary plane perpendicular to the horizontal plane and making an angle of 45°, measured as shown, with the front plane. The auxiliary plane is at the right and turned on its horizontal trace.

Locate the horizontal axis 2 inches from the lower border line and the intersection of the horizontal trace with the horizontal axis $2\frac{3}{4}$ inches from the left border line.

Problem 18.—A point is $1\frac{5}{8}$ inches from the front plane and $1\frac{1}{4}$ inches from the horizontal plane. Find its projection on an auxiliary plane perpendicular to the horizontal plane and making an angle of 60° with the front plane, measured as in Fig. 12. The auxiliary plane is at the right and turned on its horizontal trace.

Exercise II — Practical Projection, Part 2 — Sheet II



Date

Name of Student, Class Letters, and Number

Locate the horizontal axis 2 inches from the lower border line, and the intersection of the horizontal trace with the horizontal axis $2\frac{3}{4}$ inches from the right border line.

7. PROBLEM 19. Sheet II.—One corner of the object shown in Fig. 13 is $1\frac{1}{2}$ inches from the front plane and $1\frac{5}{8}$ inches from the horizontal plane. Find its projection on an auxiliary plane making an angle of 60°, as shown in Fig. 13, with the horizontal plane and being perpendicular to the front plane. The auxiliary plane is at the right and turned on its horizontal trace.

SOLUTION.—Referring to the reduced copy of Sheet II, Exercise II, draw the horizontal axis $a\,b$ in any convenient location, say 2 inches from the upper border line, placing the end b $2\frac{3}{4}$ inches from the left border line; draw the front trace $b\,c$. Since the auxiliary plane is perpendicular to the front plane, its horizontal trace is perpendicular to the horizontal axis; consequently, through the point b where the front trace intersects the horizontal axis draw a line $b\,d$ perpendicular to $a\,b$; the line $b\,d$ is the horizontal trace. In any convenient location draw a projection line $e\,f$ and on it locate the projections e and f, $1\frac{1}{2}$ inches and $1\frac{5}{8}$ inches, respectively, from the horizontal axis. Through the projection e draw a projection line perpendicular to the horizontal trace and extending sufficiently far into the auxiliary plane. Through the projection f draw a projection line $f\,g$ perpendicular to the front trace. On the projection line drawn through the horizontal trace lay off $h\,i = b\,g$; i is the projection of the point on the auxiliary plane.

PROBLEM 20.—An auxiliary plane makes an angle of 45° (measured as in Fig. 13) with the horizontal plane and is perpendicular to the front plane; it is situated at the right and turned on its horizontal trace. Find the projection on the auxiliary plane of a point that is $1\frac{1}{4}$ inches from the front plane and $1\frac{9}{16}$ inches from the horizontal plane.

Locate the horizontal axis 2 inches from the upper border line, and the horizontal trace $2\frac{3}{4}$ inches from the right border line.

PROBLEM 21.—An auxiliary plane makes an angle of 60° (measured as in Fig. 13) with the horizontal plane and is perpendicular to the front plane. Find on it the projection of a point $1\frac{5}{8}$ inches from the front plane and $1\frac{3}{4}$ inches from the horizontal plane, the auxiliary plane being at the right and turned on its horizontal trace. Use the graphical method indicated on the reduced copy of Sheet II, Exercise II.

Locate the horizontal axis 2 inches from the lower border line and the horizontal trace $2\frac{3}{4}$ inches from the left border line.

PROBLEM 22.—An auxiliary plane is perpendicular to the horizontal plane, is at the left, and makes an angle of 60° with the front plane, measured as shown in Fig. 14. The

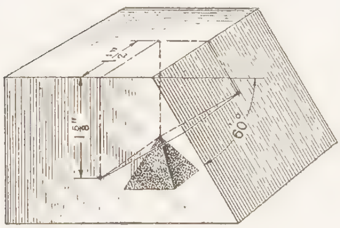


FIG. 13

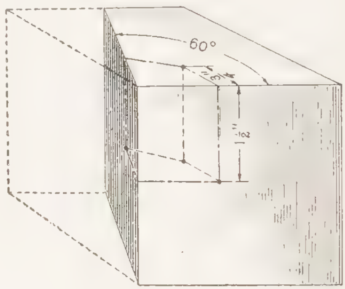
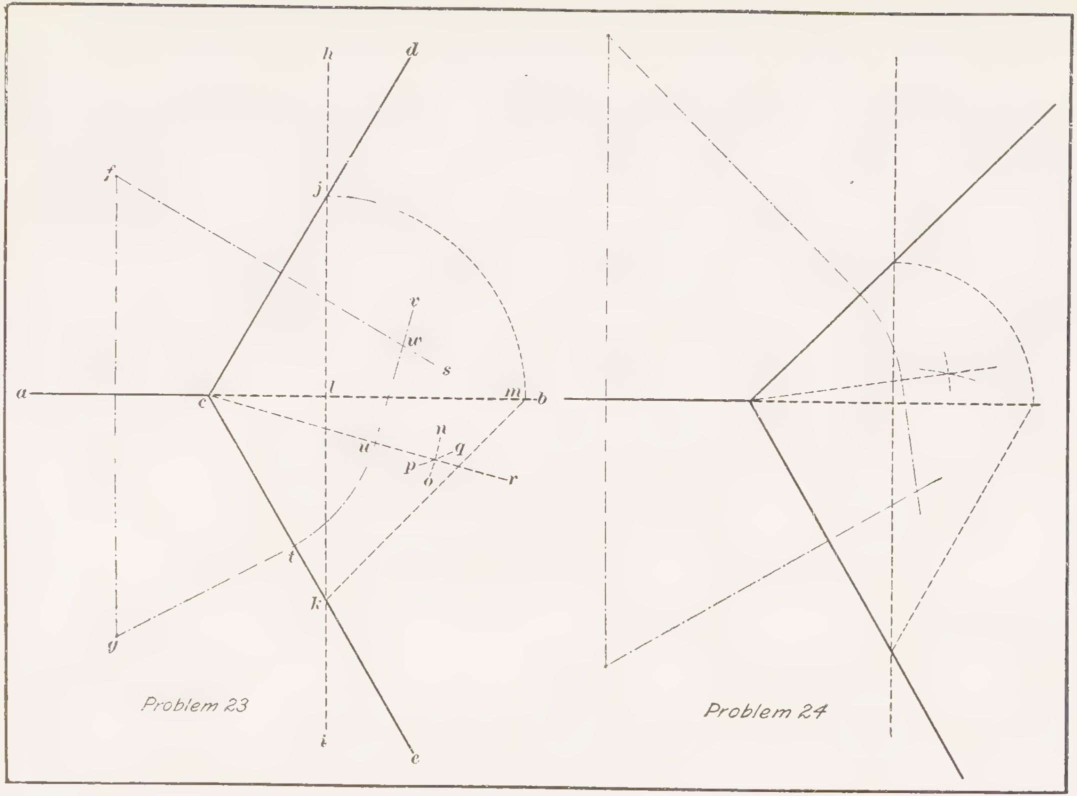


FIG. 14

auxiliary plane having been turned on its front trace, find on it the projection of a point $\frac{3}{4}$ inch from the front plane and $1\frac{1}{2}$ inches from the horizontal plane. Use the graphical method indicated on the reduced copy of Sheet II, Exercise II.

Locate the horizontal axis 2 inches from the lower border line and the front trace $2\frac{3}{4}$ inches from the right border line.

8. PROBLEM 23. Sheet III.—An auxiliary plane is oblique to the three principal planes and so inclined that its horizontal trace and front trace make an angle of 60° (measured as shown in Fig. 15) with the horizontal axis. The auxiliary plane being at the right and turned on its horizontal trace, find on it the projection of a corner of the object shown, the corner being situated $2\frac{1}{4}$ inches from the front plane and $2\frac{1}{2}$ inches from the horizontal plane.



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Solution.—Referring to the reduced copy of Sheet III, Exercise II, draw the horizontal axis or base line $a\,b$ 4 inches from the upper border line, and at an angle of 60° with it draw in any convenient location the horizontal trace $c\,d$ and front trace $c\,e$. The point c may be located $2\frac{1}{8}$ inches from the left border line. A consideration of Fig. 15 should make clear why the traces incline in the directions shown. In any convenient location draw a projection line $f\,g$ perpendicular to the horizontal axis and on it lay off the projections f and g of the point $2\frac{1}{4}$ inches above and $2\frac{1}{2}$ inches below the horizontal base line. Since the auxiliary plane is turned on its horizontal trace, it becomes necessary to find the direction of the revolved front trace. To do this, draw in any convenient location a perpendicular $h\,i$ to the horizontal axis and intersecting the traces at j and k and the horizontal axis at l; this perpendicular $h\,i$ contains the side axis $l\,h$ and vertical axis $l\,i$ of a side plane. With the origin l as a center and a radius $l\,j$, describe an arc intersecting the horizontal axis at m. Join k and m by a straight line; its length $k\,m$ is the length of a side trace corresponding to the length $c\,j$ of the horizontal trace and length $c\,k$ of the front trace. Next, with c as a center and $c\,k$ as a radius, describe an arc $n\,o$; with j as a center and $k\,m$ as a radius, describe an arc $p\,q$ intersecting the arc $n\,o$. Through the intersection of the arcs $n\,o$ and $p\,q$ and the intersection c of the traces draw the straight line $c\,r$, which gives the position of the revolved front trace. Through the projection f draw a straight line $f\,s$ perpendicular to the horizontal trace $c\,d$ and extending sufficiently far into the auxiliary plane. Through the projection g draw a straight line perpendicular to the front trace $c\,e$ and intersecting it at t. With $c\,t$ as a radius and c as a center, describe an arc intersecting the revolved front trace $c\,r$ at u. At u erect a perpendicular $u\,v$ on the revolved front trace; its intersection w with the projection line $f\,s$ is the projection of the given point on the auxiliary plane.

Problem 24.—A point is $3\frac{3}{4}$ inches from the front plane and $2\frac{3}{4}$ inches from the horizontal plane. Find its projection

on an auxiliary plane located at the right, turned on its front trace, and so inclined that its horizontal trace makes an angle of 45° with the horizontal axis, and the front trace makes an

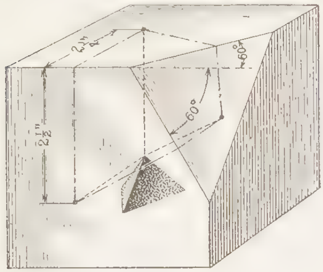


FIG. 15

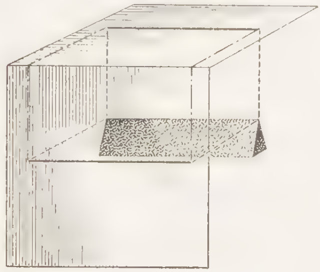


FIG. 16

angle of 60° with the horizontal axis, both angles measured in the direction indicated in Fig. 15.

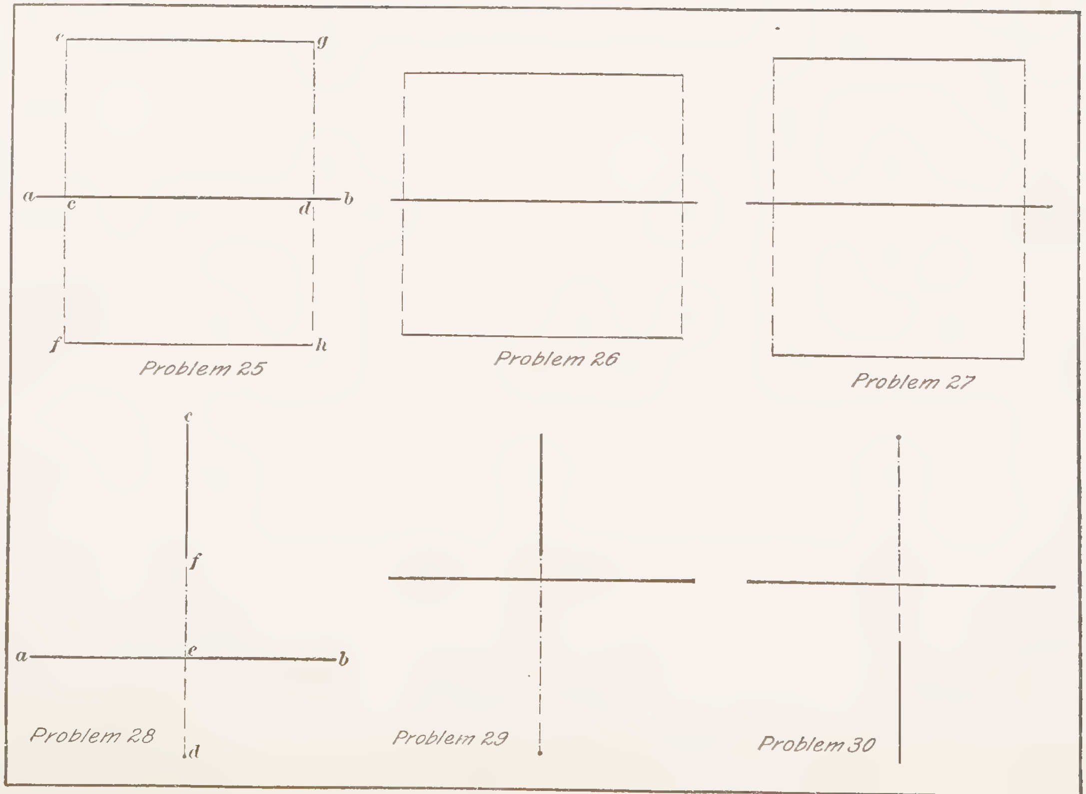
Locate the horizontal axis 4 inches from the upper border line and the intersection of the traces with the horizontal axis $3\frac{1}{4}$ inches from the right border line.

PROJECTION OF LINES

EXERCISE III

9. Projection of Lines Parallel and Perpendicular to Principal Planes.—There are in this exercise three sheets containing, in all, fourteen problems. The six problems on the first sheet relate to the projection of a straight line on two planes of projection, and those on the second and third sheets relate to the projection of a straight line on the three principal planes. In all the problems of Exercise III the straight line is parallel to two principal planes and perpendicular to the third.

PROBLEM 25.—The upper edge of a wedge is a straight line $2\frac{9}{16}$ inches long, as shown in Fig. 16, is parallel to the horizontal and front planes, and is $1\frac{5}{8}$ inches from the front plane and $1\frac{1}{2}$ inches from the horizontal plane. Show its projections on these two planes.


Problem 25
Problem 26
Problem 27
Problem 28
Problem 29
Problem 30

Solution.—Referring to the reduced copy of Sheet I, Exercise III, draw a straight line $a\,b$ 2 inches from the upper border line and of any convenient length; this line represents the horizontal axis, or base line. On this base line lay off the points c and d $2\frac{9}{16}$ inches apart and through these points draw projection lines $e\,c\,f$ and $g\,d\,h$ perpendicular to the horizontal base line. On the horizontal plane lay off on the projection lines the distances $c\,e$ and $d\,g = 1\frac{5}{8}$ inches, and on the front plane the distances $c\,f$ and $d\,h = 1\frac{1}{2}$ inches. Join e and g, and f and h, by the straight lines $e\,g$ and $p\,h$, which are the required projections of the given edge.

It will be obvious that projecting a straight line resolves itself into projecting two points—its two ends.

Instead of solving the problem as just explained, it may be solved in other but equivalent ways. Thus, indefinite lines may be drawn parallel to the horizontal base line and at distances of $1\frac{5}{8}$ and $1\frac{1}{2}$ inches from it. Then, on one of these lines the distance $e\,g$ or $f\,h$ may be laid off $= 2\frac{9}{16}$ inches, and through the points thus laid off projection lines may be drawn to the other indefinite line to locate the projection. Or, after drawing the projection lines $e\,f$ and $g\,h$ $2\frac{9}{16}$ inches apart, on one of them, say $e\,f$, lay off $c\,e = 1\frac{5}{8}$ 'inches and $c\,f = 1\frac{1}{2}$ inches, and then draw through e and f lines parallel to the base line and intersecting the projection line $g\,h$ at g and h. The question of which method to adopt is entirely one of convenience and personal choice.

Problem 26.—Show on the horizontal and front planes the projection of a straight line $2\frac{7}{8}$ inches long, and $1\frac{5}{16}$ inches from the front plane and $1\frac{3}{8}$ inches from the horizontal plane, the line being parallel to both planes.

Locate the horizontal axis 2 inches from the upper border line.

Problem 27.—A straight line $2\frac{9}{16}$ inches long is parallel to the horizontal and front planes. It is $1\frac{1}{2}$ inches from the front plane and $1\frac{9}{16}$ inches from the horizontal plane. Show its projections on the two planes mentioned.

Draw the horizontal axis 2 inches from the top border line.

PROBLEM 28.—A straight edge of a solid is $1\frac{3}{8}$ inches long, is parallel to the horizontal plane, and perpendicular to the front plane, as shown in Fig. 17. The end nearest the front plane is 1 inch from it and the line is 1 inch below the horizontal plane. Show the projections of the edge on the horizontal and front planes.

SOLUTION.—Referring to the reduced copy of Sheet I, Exercise III, draw the horizontal axis $a\,b$ $1\frac{5}{16}$ inches from the lower border line and draw a projection line $c\,d$. Lay off the distances $e\,d$ and $e\,f = 1$ inch and $f\,c = 1\frac{3}{8}$ inches. The line $c\,f$ is the horizontal projection of the edge, and the point d is its projection on the front plane.

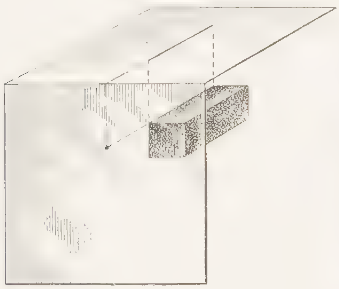


FIG. 17

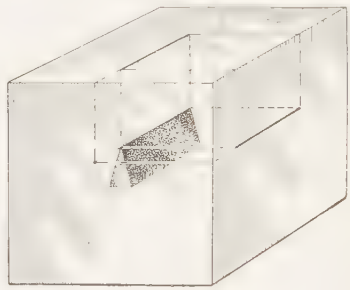


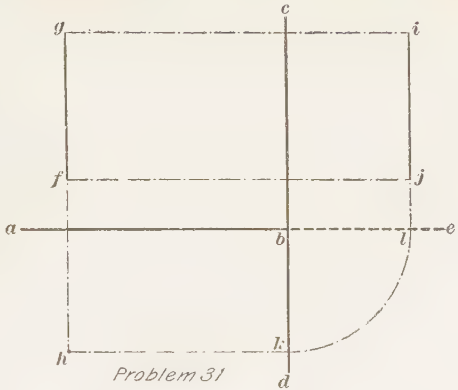
FIG. 18

It is an axiom of orthographic projection that when a line is perpendicular to a plane of projection, its projection on that plane is a point.

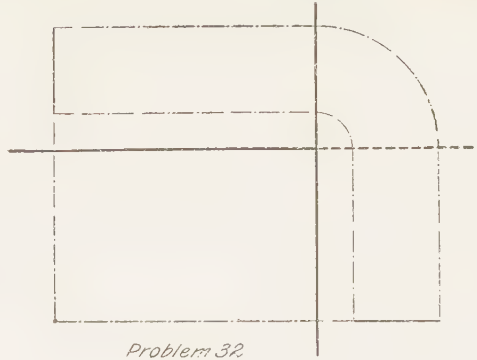
PROBLEM 29.—A straight line $1\frac{1}{4}$ inches long is perpendicular to the front plane and parallel to the horizontal plane, as in Fig. 17. The line is $1\frac{3}{4}$ inches from the horizontal plane and the end nearest the front plane is $\frac{1}{4}$ inch from it. Show its projection on the two planes mentioned.

Locate the horizontal axis $2\frac{1}{2}$ inches from the lower border line.

PROBLEM 30.—A straight line $1\frac{1}{4}$ inches long is parallel to the front plane and perpendicular to the horizontal plane. The end nearest the horizontal plane is $\frac{9}{16}$ inch from it, and

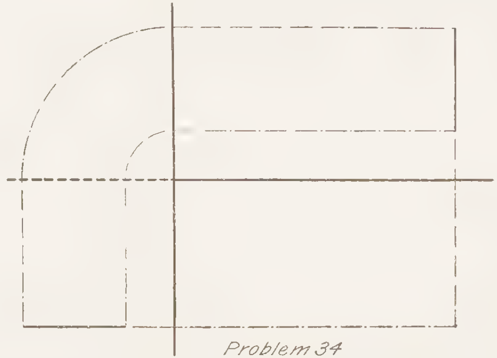


Problem 31



Problem 32

Problem 33



Problem 34

Date

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the line is $1\frac{1}{2}$ inches from the front plane. Show its projection on the horizontal and the front plane.

Locate the horizontal axis $2\frac{1}{8}$ inches from the lower border line.

10. Problem 31. Sheet II.—One straight edge $1\frac{1}{2}$ inches long, of the object shown in Fig. 18, is perpendicular to the front plane and the end nearest the plane is $\frac{1}{2}$ inch from it. The edge is $1\frac{1}{4}$ inches below the horizontal plane and $2\frac{1}{4}$ inches from the side plane. Show the projections of the edge on the three principal planes, the side plane being at the right of the horizontal plane.

Solution.—Bearing in mind that when a straight line is perpendicular to one plane of projection, it is parallel to the other two principal planes, and referring to the reduced copy of Sheet II, Exercise III, draw the horizontal axis $a\,b$ $2\frac{3}{8}$ inches from the upper border line; perpendicular to $a\,b$ and in any convenient location, say 3 inches from the left border line, draw the line $c\,d$, of which $b\,c$ is the side axis and $b\,d$ the vertical axis. Also produce the horizontal axis $a\,b$ beyond the point of origin, $b\,e$ then being the revolved position of the vertical axis. To the left of $c\,d$ and at a distance of $2\frac{1}{4}$ inches from it draw a projection line perpendicular to the horizontal axis, and hence parallel to the side and vertical axes. On this projection line locate the points f, g, and h, the point f being $\frac{1}{2}$ inch from $a\,b$, the point g being $1\frac{1}{2}$ inches from f, and the point h being $1\frac{1}{4}$ inches from $a\,b$. The straight line joining f and g is the horizontal projection and the point h the front projection of the given edge. Through f and g draw projection lines into the side plane; these lines, since they are perpendicular to the side axis, are parallel to the horizontal axis $a\,b$. On one of these projection lines lay off a point $1\frac{1}{4}$ inches to the right of the side axis $b\,c$ and draw the line $i\,j$ parallel to the side axis; $i\,j$ is the projection on the side plane. Or, draw a projection line $h\,k$ to the vertical axis $b\,d$ and with the point of origin b as a center and a radius $b\,k$ draw an arc intersecting the revolved vertical axis $b\,e$ at l. Through l draw a line perpendicular to the revolved vertical

axis and intersecting at i and j the projection lines drawn through g and f; the points of intersection i and j are the ends of the line showing the projection of the given edge on the side plane.

PROBLEM 32.—A straight line $\frac{7}{8}$ inch long is parallel to the horizontal and side planes and perpendicular to the front plane. The end nearest the front plane is $\frac{3}{8}$ inch from it, and the line is $2\frac{11}{16}$ inches from the side plane, and $1\frac{3}{4}$ inches from the horizontal plane. Show the projections of the line on the three principal planes, the side plane being at the right of the front plane.

Locate the horizontal axis $1\frac{11}{16}$ inches from the upper border line and the vertical axis $2\frac{1}{16}$ inches from the right border line.

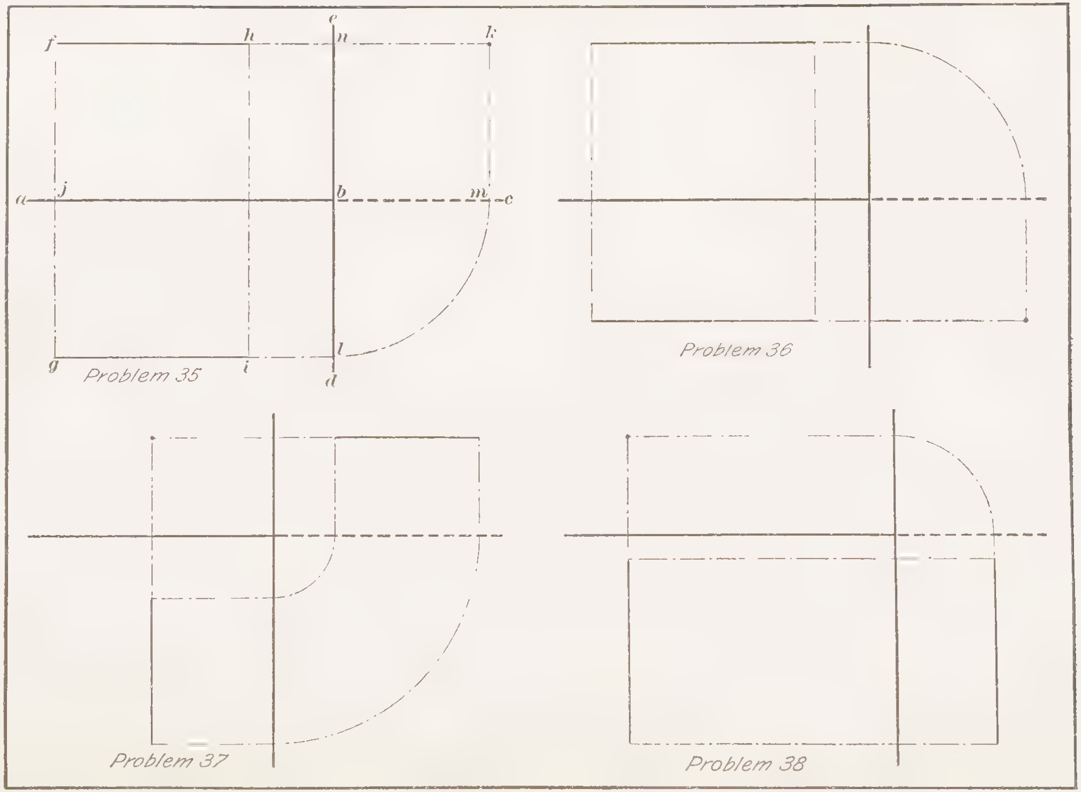
PROBLEM 33.—A straight line $1\frac{1}{16}$ inches in length is perpendicular to the front plane. The end nearest the front plane is $\frac{1}{2}$ inch from it; the line is $2\frac{3}{4}$ inches from the side plane and $1\frac{1}{2}$ inches from the horizontal plane. Show the projections of the line on the three principal planes, the side plane being at the left of the horizontal plane.

Locate the horizontal axis 2 inches from the lower border line and the vertical axis $2\frac{1}{8}$ inches from the left border line.

PROBLEM 34.—A straight line $1\frac{1}{16}$ inches long is perpendicular to the front plane and the end nearest that plane is $\frac{1}{2}$ inch from it. The line is $1\frac{1}{2}$ inches from the horizontal plane and $2\frac{7}{8}$ inches from the side plane. Show its projections on the three principal planes, the side plane being at the left of the front plane.

Locate the horizontal axis 2 inches from the lower border line and the vertical axis $3\frac{1}{2}$ inches from the right border line.

11. PROBLEM 35. Sheet III.—An edge of a cube, 2 inches long, is parallel to the front plane and horizontal plane, as shown in Fig. 19, and $1\frac{5}{8}$ inches from these two planes. The end nearest the side plane is $\frac{7}{8}$ inch from it. Show the projections of the edge on the three principal planes, the side plane being at the right of the horizontal plane.


a
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Problem 35
Problem 36
Problem 37
Problem 38

Solution.—Referring to the reduced copy of Sheet III, Exercise III, draw the horizontal axis $a\,b$ and revolved vertical axis $b\,c$, 2 inches from the upper border line, and perpendicular thereto the vertical axis $b\,d$ and side axis $b\,e$ about $3\frac{3}{8}$ inches from the left border line. At distances of $\frac{7}{8}$ inch and $2+\frac{7}{8}=2\frac{7}{8}$ inches, and to the left of the side and vertical axes, draw projection lines $f\,g$ and $h\,i$. On one of these projection lines, as $f\,g$ for instance, lay off the distances $j\,f$ and $j\,g=1\frac{5}{8}$ inches, and draw the projections $f\,h$ and $g\,i$ parallel to the horizontal axis $a\,b$. Through h draw a projection line $h\,k$ extending sufficiently far into the side plane; through i draw a projection line intersecting the vertical axis $b\,d$ at l. With $b\,l$ as a radius and the origin b as a center, describe an arc intersecting the revolved vertical axis $b\,c$ at m. Through m draw a perpendicular intersecting at k the projection line drawn through h. The point of intersection k is the projection of the given edge on the side plane.

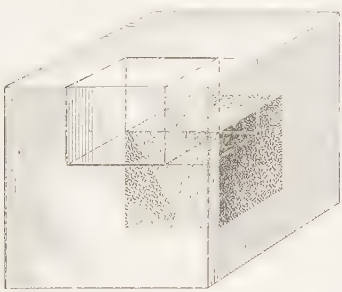


Fig. 19

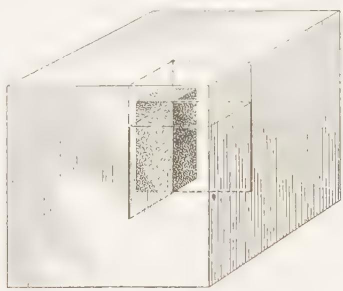


Fig. 20

Instead of proceeding to find the projection in the side plane as just described, it is often more convenient to find the projection by laying off, by direct measurement, on the projection line drawn into the side plane and from the side axis the distance the given line is from the horizontal plane; that is, in this case make $n\,k=1\frac{5}{8}$ inches.

Problem 36.—A straight line $2\frac{5}{16}$ inches long is parallel to the horizontal and front planes; it is $1\frac{1}{4}$ inches from the horizontal plane and $1\frac{5}{8}$ inches from the front plane. The

end nearest the side plane is $\frac{9}{16}$ inch from it. Show the projections of the line on the three principal planes, the side plane being at the right of the front plane.

Locate the horizontal axis 2 inches from the upper border line and the side axis $2\frac{1}{16}$ inches from the right border line.

PROBLEM 37.—One straight edge of the solid shown in Fig. 20 is $1\frac{1}{2}$ inches long, is perpendicular to the horizontal plane, and the end nearest that plane is $\frac{5}{8}$ inch from it. The side plane being at the right of the horizontal plane, show the three projections of the edge. The line is $1\frac{1}{4}$ inches from the side plane and 1 inch from the front plane.

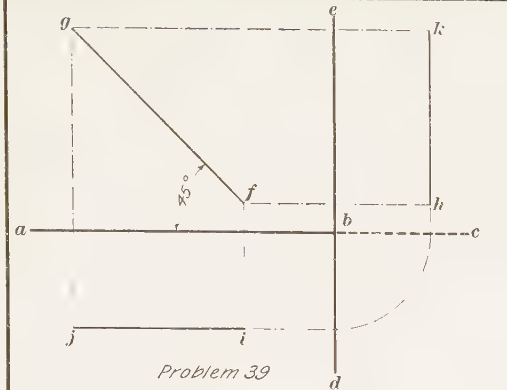
Locate the horizontal axis $2\frac{9}{16}$ inches from the lower border line, and the vertical axis $2\frac{3}{4}$ inches from the left border line.

PROBLEM 38.—A straight line has a length of $1\frac{7}{8}$ inches and is parallel to the front and side planes; it is 1 inch from the front plane and $2\frac{3}{4}$ inches from the side plane. The end nearest the horizontal plane is $\frac{1}{4}$ inch from it. The side plane being at the right of the front plane, show the three projections of the line.

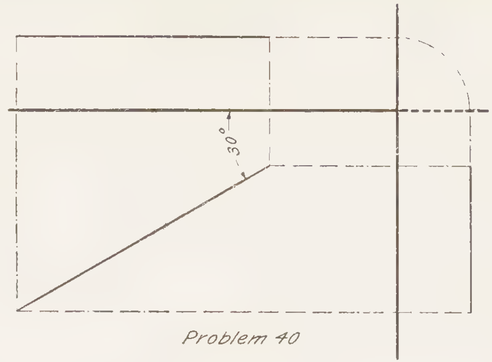
Locate the horizontal axis $2\frac{9}{16}$ inches from the lower border line and the vertical axis $1\frac{13}{16}$ inches from the right border line.

EXERCISE IV

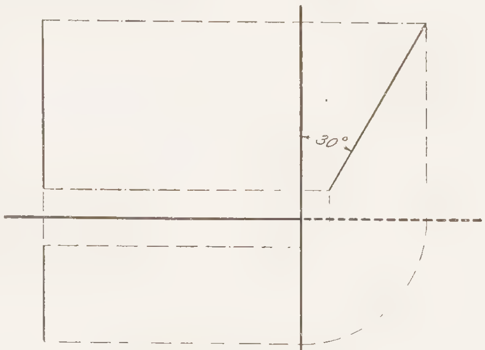
12. Projection of Lines Oblique to Principal Planes.—Exercise IV consists of four sheets containing eighteen problems. The four problems of Sheet I relate to the projection of a straight line that is parallel to one and inclined to two of the principal planes. On Sheet II are presented four problems of projecting a straight line inclined to all three principal planes. The four problems on Sheet III relate to the projection of a straight line inclined to all three planes on an auxiliary plane perpendicular to one principal plane and inclined to two. On Sheet IV are given six problems relating to finding the true length of a line inclined to the three principal planes.



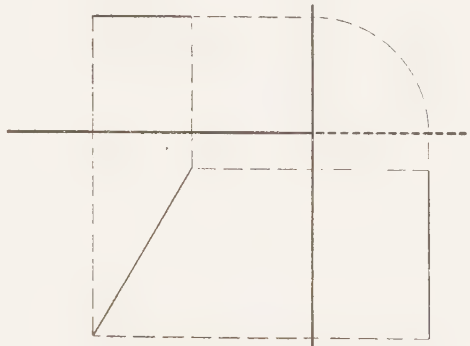
Problem 39



Problem 40



Problem 41



Problem 42

Date

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PROBLEM 39.—As shown in Fig. 21, a straight edge $2\frac{1}{2}$ inches long is parallel to the horizontal plane and makes an angle of 45° with the front plane. The end nearest the front plane is $\frac{9}{32}$ inch from that plane and $\frac{15}{16}$ inch from the side plane. The edge is 1 inch from the horizontal plane. Show the projections of the edge on the three principal planes, the side plane being at the right of the horizontal plane.

SOLUTION.—Referring to the reduced copy of Sheet I, Exercise IV, draw the horizontal axis $a\,b$ and the revolved vertical axis $b\,c$ $2\frac{3}{8}$ inches from the upper border line, the two being a single straight line; in any convenient location, say $3\frac{3}{8}$ inches from the border line, draw a straight line $d\,e$ per-

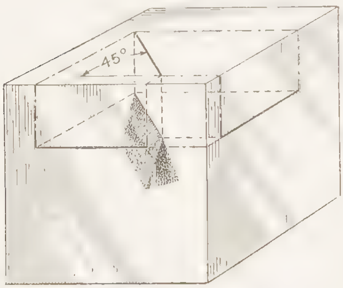


FIG. 21

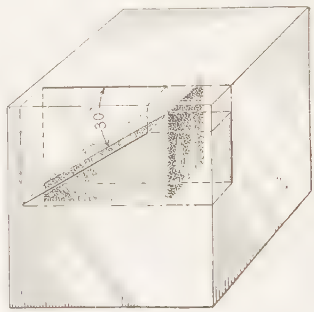


FIG. 22

pendicular to the horizontal axis. The part $b\,d$ represents the vertical axis and the part $b\,e$ the side axis. Locate the one end f of the projection of the given line in the horizontal plane $\frac{15}{16}$ inch to the left of the side axis and $\frac{9}{32}$ inch from the horizontal axis and draw a straight line $f\,g$ at an angle of 45° with the horizontal axis $a\,b$, making $f\,g = 2\frac{1}{2}$ inches. Through the points f and g draw projection lines $f\,h$ and $f\,i$ and $g\,k$ and $g\,j$ into the front and side planes. From the horizontal axis downwards, and to the right of the side axis, lay off on one of the projection lines a distance of 1 inch, and through the points thus laid off, as j and k for instance, or i and h, draw the front projection $j\,i$ and side projection $k\,h$ parallel to $a\,b$ and $b\,c$, respectively.

Or, after the projection has been drawn in the horizontal plane, draw the projection in one of the other two planes and locate the projection in the third plane by the graphical method indicated in the reduced copy of Sheet I, Exercise IV.

Since the given line is parallel to one of the principal planes of projection, its projection in the plane to which it is parallel will show the given line in its true length; thus, in Problem 39, $f\,g$ is the true length.

PROBLEM 40.—A straight edge of the solid shown in Fig. 22 is 3 inches long, is parallel to the front plane, and is inclined 30° to the horizontal plane in the direction shown. The upper end of the edge is $\frac{9}{16}$ inch from the horizontal plane and $1\frac{5}{16}$ inches from the side plane; the edge is $\frac{3}{4}$ inch from the front plane. Show the projections of the edge on the principal planes, the side plane being at the right of the front plane.

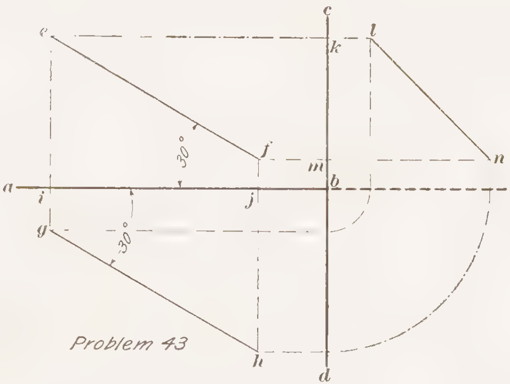
Locate the horizontal axis $1\frac{1}{4}$ inches from the upper border line and the side axis $1\frac{1}{4}$ inches from the right border line.

PROBLEM 41.—A straight edge of the wedge shown in Fig. 23 is 2 inches long, is parallel to the side plane, and is inclined 30° to the horizontal plane in the direction shown. It is located $2\frac{21}{32}$ inches from the side plane, and its upper end is $\frac{9}{32}$ inch from both the horizontal and the front plane. Show its projections on the three principal planes, the side plane being at the right of the horizontal plane.

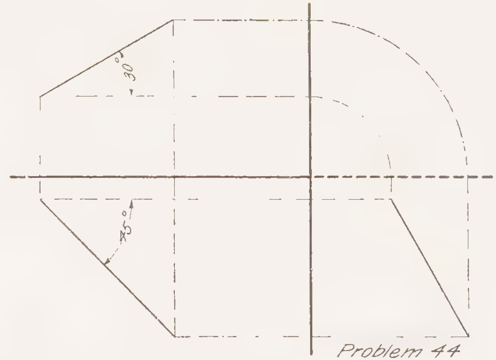
Locate the horizontal axis $1\frac{5}{8}$ inches from the lower border line and the side axis $3\frac{5}{16}$ inches from the left border line.

PROBLEM 42.—A straight line 2 inches long is inclined to the horizontal plane, as the edge in Fig. 22, except that the angle is 60° instead of 30°; the line is parallel to the front plane and $1\frac{3}{16}$ inches from it. The upper end of the line is $1\frac{1}{4}$ inches from the side plane and $\frac{3}{8}$ inch from the horizontal plane. Show its projections on the three principal planes, the side plane being at the right of the front plane.

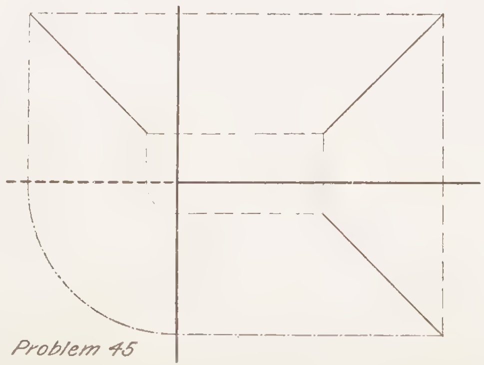
Locate the horizontal axis $2\frac{1}{2}$ inches from the lower border line and the vertical axis $2\frac{1}{16}$ inches from the right border line.

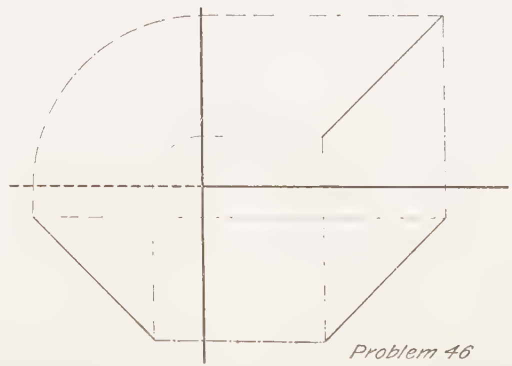


Problem 43



Problem 44


Problem 45


Problem 46

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13. PROBLEM 43. Sheet II.—A straight edge of an object is inclined to the three principal planes, as indicated in Fig. 24, so that its projections in the horizontal and front planes make an angle of 30° with the horizontal axis. The projection in the horizontal plane is $2\frac{1}{2}$ inches long. The upper end of the edge is $\frac{7}{16}$ inch from the horizontal plane, $1\frac{9}{16}$ inches from the front plane, and $2\frac{7}{8}$ inches from the side plane. Show the projections of the edge on the three principal planes, the side plane being at the right of the horizontal plane.

SOLUTION.—Referring to the reduced copy of Sheet II, Exercise IV, draw the horizontal base line, or axis $a\,b$, 2 inches from the upper border line; perpendicular to $a\,b$ and at any convenient place, say $3\frac{7}{16}$ inches from the left border line,

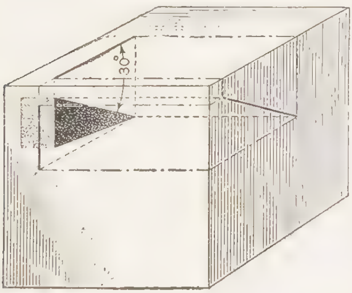


FIG. 23

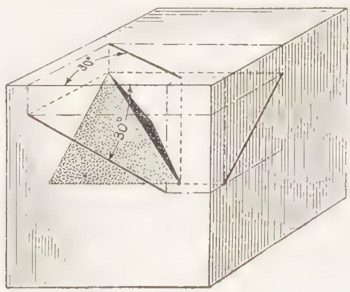


FIG. 24

draw the line $c\,b\,d$, of which $b\,c$ is the side axis and $b\,d$ the vertical axis. In the horizontal plane locate the upper end of the edge by locating its projection e $2\frac{7}{8}$ inches from the side axis $b\,c$ and $1\frac{9}{16}$ inches from the horizontal axis $a\,b$. From the point e at an angle of 30° with the horizontal axis draw a straight line $e\,f$ $2\frac{1}{2}$ inches long, which is the horizontal projection. From the points e and f draw projection lines into the front plane and side plane. On the projection line drawn from e into the front plane locate the upper end of the edge by locating its projection g $\frac{7}{16}$ inch from the horizontal axis. From g draw a straight line at an angle of 30° with the horizontal axis and intersecting at h the projection line drawn from f; $g\,h$ will be the front projection.

To find the projection on the side plane, on the projection lines drawn through e and f into the side plane, lay off $k\,l = i\,g$, and $m\,n = j\,h$, and join l and n by a straight line, which is the projection of the given edge on the side plane. Or, find the points l and n by the graphical method indicated.

PROBLEM 44.—A straight line is inclined so that its horizontal projection, as shown in Fig. 25, makes an angle of 30° with the horizontal axis, and its front projection an angle of 45° with that axis. The projection in the front plane is 2 inches long; the upper end of the line is $\frac{7}{32}$ inch from the horizontal plane, $\frac{27}{32}$ inch from the front plane, and $2\frac{13}{16}$ inches from the side plane. Show the projections on the three

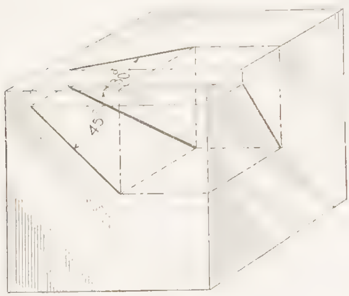


FIG. 25

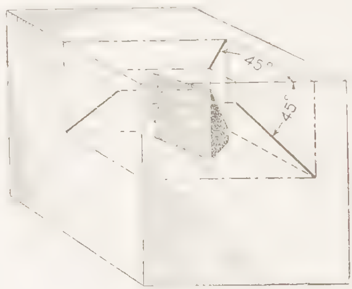


FIG. 26

principal planes, the side plane being at the right of the front plane.

Locate the horizontal axis 2 inches from the upper border line and the side axis $2\frac{1}{8}$ inches from the right border line.

PROBLEM 45.—A straight line whose projection in the front plane is $1\frac{3}{4}$ inches long is inclined to the three principal planes in such a way that its projections in the horizontal and front planes make an angle of 45° with the horizontal axis, measured as shown in Fig. 26. The upper end of the line is $1\frac{1}{2}$ inches from the side plane, $\frac{1}{2}$ inch from the front plane, and $\frac{5}{16}$ inch from the horizontal plane. Show the projections of the line on the three principal planes, the side plane being at the left of the horizontal plane.

Locate the horizontal axis 2 inches from the lower border line and the side axis $2\frac{1}{16}$ inches from the left border line.

PROBLEM 46.—A solid has a straight edge whose projection in the horizontal plane is $1\frac{3}{4}$ inches long, and is inclined to the three principal planes so that its projections in the horizontal and front planes make an angle of 45° with the horizontal axis, measured as shown in Fig. 27. The upper end of the edge is $2\frac{1}{2}$ inches from the side plane, $1\frac{3}{4}$ inches from the front plane, and $\frac{5}{16}$ inch from the horizontal plane. Show the projections of the edge on the three principal planes, the side plane being at the left of the front plane.

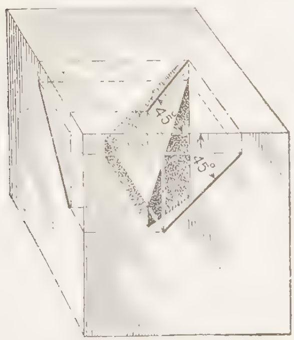


FIG. 27

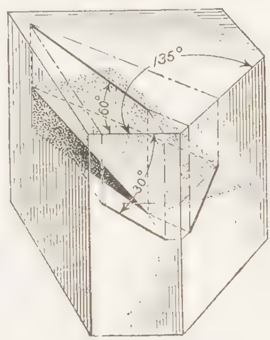
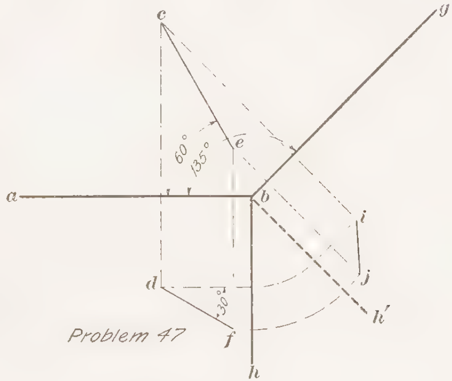


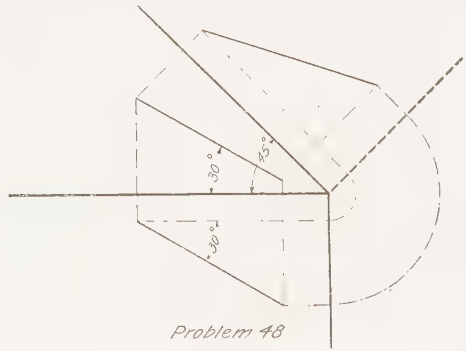
FIG. 28

Locate the horizontal axis 2 inches from the lower border line and the side axis $3\frac{3}{8}$ inches from the right border line.

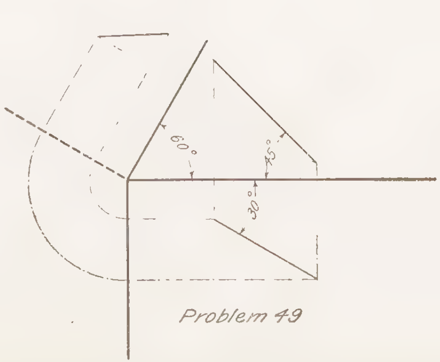
14. Projection of Lines on Auxiliary Planes. PROBLEM 47. Sheet III.—A straight edge is inclined to the three principal planes so that its projection in the horizontal plane makes an angle of 60° with the horizontal axis, measured as shown in Fig. 28, and its projection in the front plane makes an angle of 30° with the horizontal axis. Show the projections of the edge on the horizontal and front planes, and on an auxiliary plane perpendicular to the horizontal plane but making an angle of 135° with the front plane. The auxiliary plane is turned on its horizontal trace. The horizontal projection of the edge is $1\frac{1}{2}$ inches long; the upper



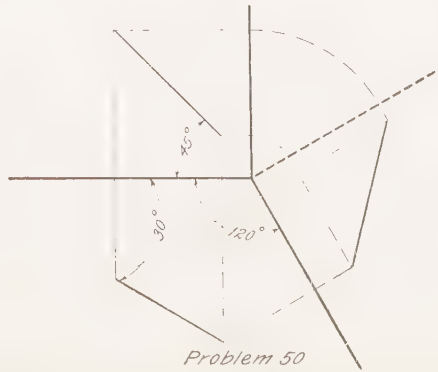
Problem 47



Problem 48



Problem 49



Problem 50

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end of the edge is $\frac{15}{16}$ inch from the horizontal plane, and $1\frac{13}{16}$ inches from the front plane.

The auxiliary plane may, in this case, be taken at any convenient distance from the edge.

SOLUTION.—Referring to the reduced copy of Sheet III, Exercise IV, draw the horizontal axis $a\,b$ $2\frac{3}{16}$ inches from the upper border line; and, in any convenient location, say, $1\frac{11}{16}$ inches from the left border line, draw a projection line $c\,d$, on which lay off the points c and d, respectively, at distances of $1\frac{13}{16}$ inches and $\frac{15}{16}$ inch from $a\,b$, thus locating the projection of the upper end of the edge in the horizontal and front planes. Through the point c draw a line $c\,e$ at an angle of 60° to $a\,b$, making $c\,e = 1\frac{1}{2}$ inches. Through e draw a projection line $e\,f$ sufficiently far into the front plane. Through the point d in the front plane draw a line at an angle of 30° with the horizontal axis and intersecting at f the projection line drawn from e; the straight line $d\,f$ is the front projection.

Next, in any convenient position in relation to the projections $c\,e$ and $d\,f$, draw the horizontal trace $b\,g$ of the auxiliary plane at an angle of 135° to the horizonal axis $a\,b$; reference to Fig. 28 will show why the trace inclines to the right. The intersection of the horizontal trace with the horizontal axis may be located $2\frac{5}{8}$ inches from the left border line. Also draw the front trace $b\,h$, which, since the auxiliary plane is perpendicular to the horizontal plane, is perpendicular to the horizontal axis. Draw the revolved front trace $b\,h'$ perpendicular to the horizontal trace. From the points c and e draw projection lines (perpendicular to $b\,g$) into the auxiliary plane; through d and f draw projection lines to the front trace $b\,h$ and transfer the two intersections to the revolved front trace by striking arcs having b as a center. At the two points of intersection on the revolved front trace erect perpendiculars intersecting the projection lines drawn from c and e in i and j; join i and j by a straight line, which is the projection of the given edge on the auxiliary plane.

PROBLEM 48.—As shown in Fig. 29, an auxiliary plane makes an angle of 45° with the front plane and is perpen-

dicular to the horizontal plane. A straight line is inclined to the different planes in such a manner that its horizontal projection and its front projection both make an angle of 30° with the horizontal axis, the direction being given in Fig. 29. The horizontal projection is $1\frac{3}{4}$ inches long and the upper end of the line is 1 inch from the front plane and $\frac{9}{32}$ inch from the horizontal plane. Show the projections on the horizontal, front, and auxiliary planes, the last having been turned on its horizontal trace. The auxiliary plane may be located in any convenient position in relation to the projections.

Locate the horizontal axis $2\frac{3}{16}$ inches from the upper border line and the front trace 2 inches from the right border line.

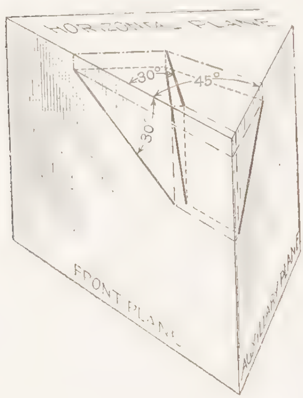


Fig. 29

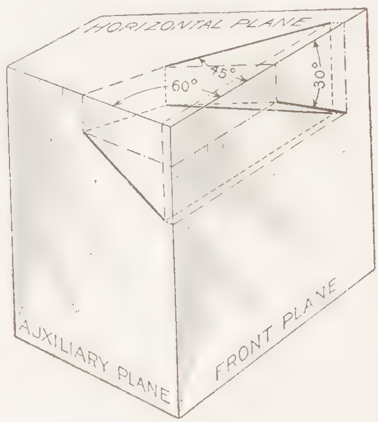


Fig. 30

Problem 49.—As shown in Fig. 30, an auxiliary plane is at the left and makes an angle of 60° with the front plane; it is perpendicular to the horizontal plane. A straight line is inclined to the several planes in such a manner that its projection in the horizontal plane makes an angle of 45°, and in the front plane of 30°, with the horizontal axis, in the directions shown in Fig. 30. The projection in the horizontal plane is $1\frac{1}{2}$ inches long, and the upper end of the line is $\frac{13}{32}$ inch from the horizontal plane and $1\frac{7}{32}$ inches from the front plane. Show the projections of the line on the horizontal, front, and auxiliary planes, the last having been turned on its

horizontal trace. The auxiliary plane may be located in any convenient position in relation to the line.

Locate the horizontal axis $2\frac{1}{16}$ inches from the lower border line and the front trace 2 inches from the left border line.

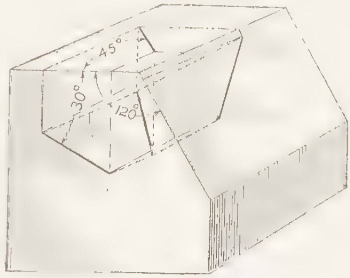


Fig. 31

Problem 50.—An auxiliary plane is at the right, as shown in Fig. 31; it is perpendicular to the front plane and makes an angle of 120° with the horizontal plane. A straight line is inclined to the several planes so that its horizontal projection makes an angle of 45°, and its front projection an angle of 30° with the horizontal axis, the inclination being as shown in Fig. 31. The horizontal projection of the line is $1\frac{17}{32}$ inches long. The auxiliary plane being located in any convenient position and turned on its front trace, shows the projections of the line on the horizontal, front, and auxiliary planes.

Locate the horizontal axis $2\frac{1}{16}$ inches from the lower border line and the horizontal trace $2\frac{13}{16}$ inches from the right border line.

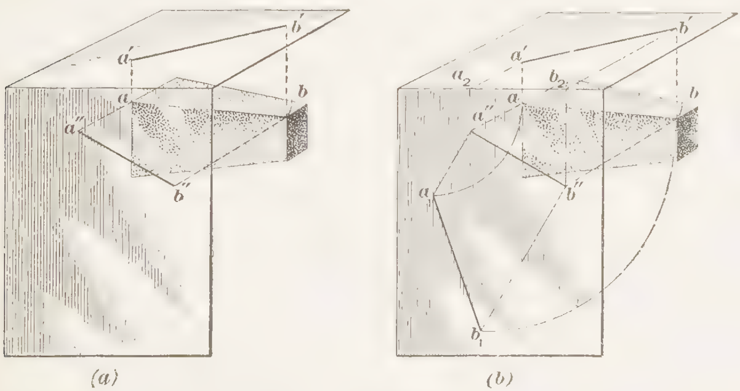
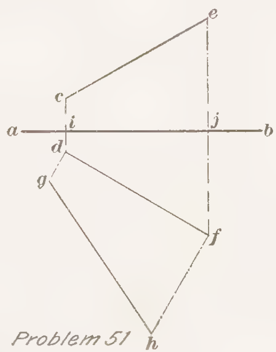
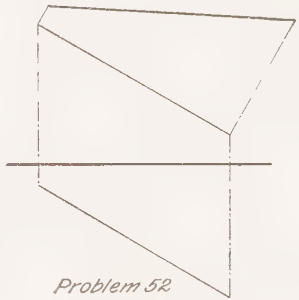


Fig. 32

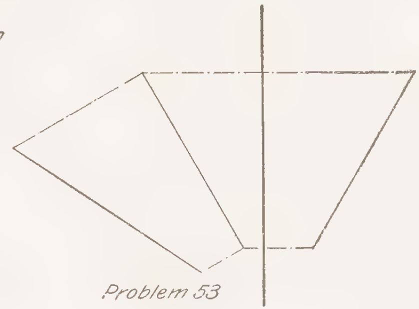
15. Finding the True Length of Lines Inclined to Principal Planes.—The six problems presented on Sheet IV



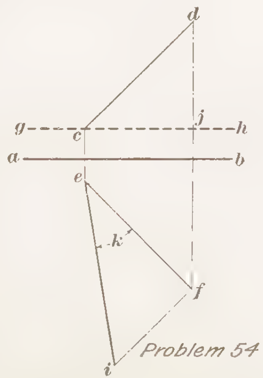
Problem 51



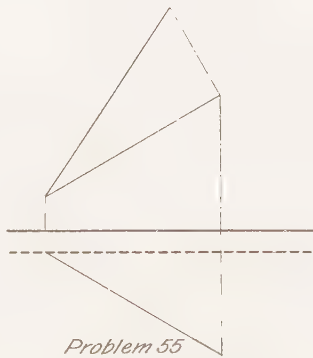
Problem 52



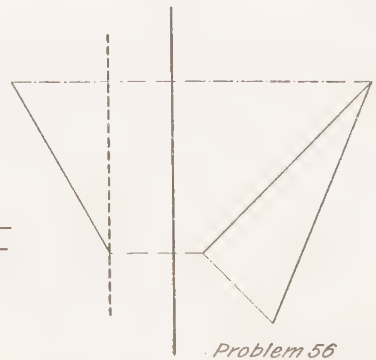
Problem 53



Problem 54



Problem 55



Problem 56

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relate to finding the true length of a line that is oblique to the three principal planes and whose projections, therefore, show foreshortened. The solution is an easy one if the principle is thoroughly understood; in order to solve the problem two projections of the line must be given. Referring to Fig. 32 (*a*), there are shown two of the principal planes; in this case the horizontal and front planes. The line $a\,b$ is shown on these planes by its projections $a'\,b'$ and $a''\,b''$. Consider the plane figure $a\,a''\,b''\,b$ as an auxiliary plane of which the boundaries are the line $a\,b$, the projectors $a\,a''$ and $b\,b''$, and the projection $a''\,b''$. The projection $a''\,b''$ may also be considered as a trace of the plane $a\,a''\,b''\,b$. In this auxiliary plane the line $a\,b$ lies in its true length; hence, if the plane is turned on its trace until it coincides with the front plane, the line $a\,b$ will show in its true length in that plane. In Fig. 32 (*b*) the plane $a\,a''\,b''\,b$ is shown turned on its trace $a''\,b''$ into the front plane; it will be apparent that $a''\,a_1 = a''\,a$, and $b''\,b_1 = b''\,b$. Furthermore, since projectors are always perpendicular to the reference planes, the lines $a''\,a_1$ and $b''\,b_1$ are perpendicular to the projection $a''\,b''$. Since the projectors $a\,a''$ and $b\,b''$ are at right angles to the front plane, they are parallel to the horizontal plane, and consequently their true length is given by their projections $a_2\,a'$ and $b_2\,b'$. Then, if on the drawing two perpendiculars are erected at the ends of the front projection $a''\,b''$ of the line, and if $a''\,a_1$ is made equal to $a_2\,a'$, and if $b''\,b_1$ is made equal to $b_2\,b'$, the distance between a_1 and b_1 is the true length of the line $a\,b$.

If it is more convenient, for any reason, to work on the horizontal plane, perpendiculars are erected at the ends a' and b' of the horizontal projection and made equal in length to the projections $a''\,a_2$ and $b''\,b_2$ of the projectors $a\,a'$ and $b\,b'$.

It does not matter in which direction the auxiliary plane whose one boundary edge is the inclined line in space is turned on its trace to bring it into the principal plane it intersects; thus, although in Fig. 32 (*b*) the auxiliary plane intersecting the front plane has been turned downwards on its trace $a''\,b''$, it may be turned upwards just as well.

The graphical solution of the problem of finding the true length of a line does not, in practice, necessarily have to be performed directly on the projection of the line; a straight line may be drawn anywhere in any convenient location, but must have the same length as one of the projections. At the ends of this line perpendiculars are erected and their lengths taken from the drawing containing the two projections.

The solution just explained gives not only the true length of the line but also shows what angle the line makes with that principal plane on which the solution was performed. Thus, in Fig. 32 (*b*), the angle between the line $a_1\, b_1$ and the projection $a''\, b''$ is the angle the line $a\, b$ makes with the front plane.

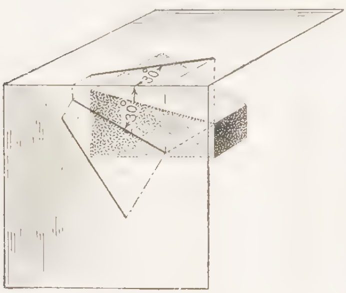


Fig. 33

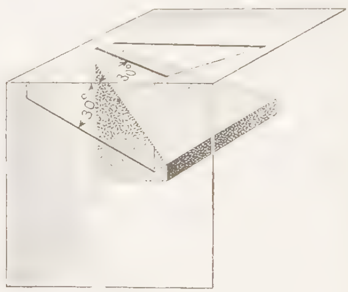


Fig. 34

16. Problem 51. Sheet 1.—A straight edge of an object is inclined in such a direction that its horizontal and front projections, as shown in Fig. 33, make an angle of 30° with the horizontal axis. The horizontal projection is $1\frac{11}{16}$ inches long, and the upper end of the edge is $\frac{11}{32}$ inch from the front plane and $\frac{7}{32}$ inch from the horizontal plane. Find the true length of the edge, showing it on the front plane.

Solution.—Referring to the reduced copy of Sheet IV, Exercise IV, draw the horizontal axis $a\, b$ $1\frac{1}{2}$ inches from the upper border line, and in any convenient place, say $\frac{3}{4}$ inch from the left border line, draw a projection line $c\, d$; locate the point c $\frac{11}{32}$ inch, and the point d $\frac{7}{32}$ inch, from the horizontal axis. From the points c and d draw lines at an angle of 30°

to the horizontal axis in the direction called for by Fig. 33; make $c\,e = 1\frac{11}{16}$ inches. Through the point e draw a projection line intersecting at f the straight line drawn from d. The line $c\,e$ is the horizontal projection and the line $d\,f$ the front projection of the given edge. At the points d and f erect lines perpendicular to $d\,f$ and make $d\,g = i\,c$, and $f\,h = j\,e$; join g and h by a straight line. The length $g\,h$ of this line is the true length of the given edge.

PROBLEM 52.—A straight edge whose projections in the horizontal and front planes are $2\frac{5}{16}$ inches long is inclined in such a direction that its horizontal and front projections make an angle of 30° with the horizontal axis, as shown in Fig. 34. The upper end of the edge is $1\frac{7}{16}$ inches from the front plane and $\frac{7}{32}$ inch from the horizontal plane. Find the true length of the edge, showing it on the horizontal plane.

Locate the horizontal axis $2\frac{1}{4}$ inches from the upper border line and the projections of the upper end of the line $3\frac{5}{8}$ inches from the left border line.

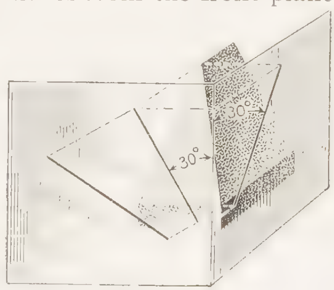


FIG. 35

PROBLEM 53.—A straight edge of a solid is inclined in such a direction toward the front and side planes, the last being at the right, that its projections make an angle of 30° with the vertical axis, as shown in Fig. 35. The projections of the edge are $2\frac{3}{32}$ inches long; the upper end of the edge is $1\frac{9}{16}$ inches from the front plane and $1\frac{1}{4}$ inches from the side plane. Find the true length of the edge, showing it on the front plane.

Locate the vertical axis 2 inches from the right border line and the projections of the upper end of the line $1\frac{3}{16}$ inches from the upper border line.

17. The solution of the problem of finding the true length of a line inclined to the three principal places that was given in Art. **15** is not the only one; by a slightly different application of the principle there explained, a somewhat

simpler solution is possible. In Fig. 36, let $a\,b$ be the given line and $a'\,b'$ and $a_1\,b_1$ its projections on two of the principal planes. Through the end of the given line that is nearest to the plane on which it is desired to find the true length (the front plane in this case) pass an auxiliary plane $c\,d\,f\,e$ parallel to that plane; obviously, the trace $c\,d$ will be parallel to the axis of the two principal planes, or the horizontal axis in this case. Let $a\,b''$ be the projection of $a\,b$ on the plane $c\,d\,f\,e$; then turn the triangular auxiliary plane $a\,b''\,b$ on its trace ab'' into the plane $cdfe$, when $a\,b_2$ will be the true length of the line. Since the projector $b''\,b$ is at right angles to the plane $c\,d\,f\,e$, the projection line $g\,b_1$ is perpendicular to the trace $c\,d$, and the straight line $b''\,b_2$ is perpendicular to the projection $a\,b''$. Now, let the triangle $a\,b_2\,b''$ be projected into the principal plane to which $c\,d\,f\,e$ is parallel; then $b_3\,b'$ is at right angles to the projection

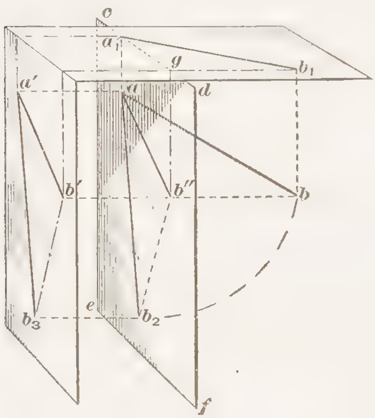


FIG. 36

$a'\,b'$, and since $b_3\,b' = b_2\,b'$, and $b_2\,b'' = b''\,b$, and $b''\,b = g\,b_1$, it follows that $b_3\,b' = g\,b_1$.

From the explanation, it follows that the solution resolves itself into constructing a right-angled triangle, of which one of the sides adjacent to the right angle has a length equal to the projection in the one principal plane. The second side adjacent the right angle has a length equal to the perpendicular distance from the trace of an auxiliary plane, parallel to the plane on which the problem is solved and passing through one end of the given line, to the other end of the projection in the second principal plane. The hypotenuse is the true length of the line.

As with the previous solution, there is no particular necessity of working directly on one of the projections; the triangle may be constructed anywhere.

It is of the utmost importance to thoroughly understand the principles underlying the problem of finding the true length of lines, as innumerable problems arise in practice, especially in sheet-metal, boiler, and similar work, that cannot be solved without full knowledge of the principles involved.

18. Problem 54.—A straight edge of an object is inclined in such a way that its horizontal and front projections make an angle of 45° with the horizontal axis, as shown in Fig. 37. The front projection is $1\frac{9}{16}$ inches long; the upper end of the edge is $\frac{5}{16}$ inch from the front plane and $\frac{7}{32}$ inch from the horizontal plane. Find on the front plane its true length, using the method described in Art. **17.**

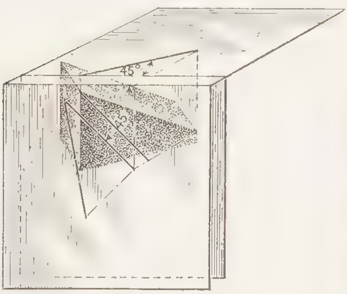


Fig. 37

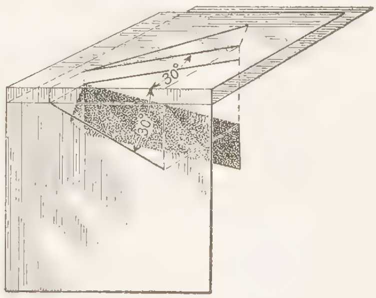


Fig. 38

Solution.—Referring to the reduced copy of Sheet IV, Exercise IV, draw the horizontal axis $a\,b$ and the projections $c\,d$ and $e\,f$ in the manner previously described, locating $a\,b$ $2\frac{3}{8}$ inches from the lower border line and c 1 inch from the left border line. Through the point c draw a straight line $g\,h$, representing the trace of an auxiliary plane parallel to the front plane, and hence parallel to the horizontal axis $a\,b$. At f erect a perpendicular and make $f\,i = j\,d$. Join e and i by a straight line, which gives the true length.

The angle k is the angle the line in space makes with the front plane.

Problem 55.—A straight edge of a solid is inclined to the three principal planes so that its projections in the horizontal

and front planes, as shown in Fig. 38, make an angle of 30° with the horizontal axis. The projection in the horizontal plane is $2\frac{3}{32}$ inches long, and the upper end of the edge is $\frac{7}{32}$ inch from the horizontal plane and $\frac{11}{32}$ inch from the front plane. Using the method described in Art. **17,** find on the horizontal plane the true length of the edge.

Locate the horizontal axis $1\frac{3}{4}$ inches from the lower border line and the projections of the upper end of the line $3\frac{11}{16}$ inches from the left border line.

PROBLEM 56.—A straight line is inclined in such a direction that its projection on the side plane, which is at the left of

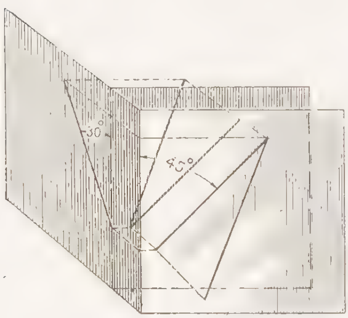


FIG. 39

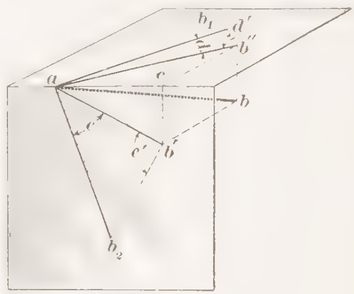


FIG. 40

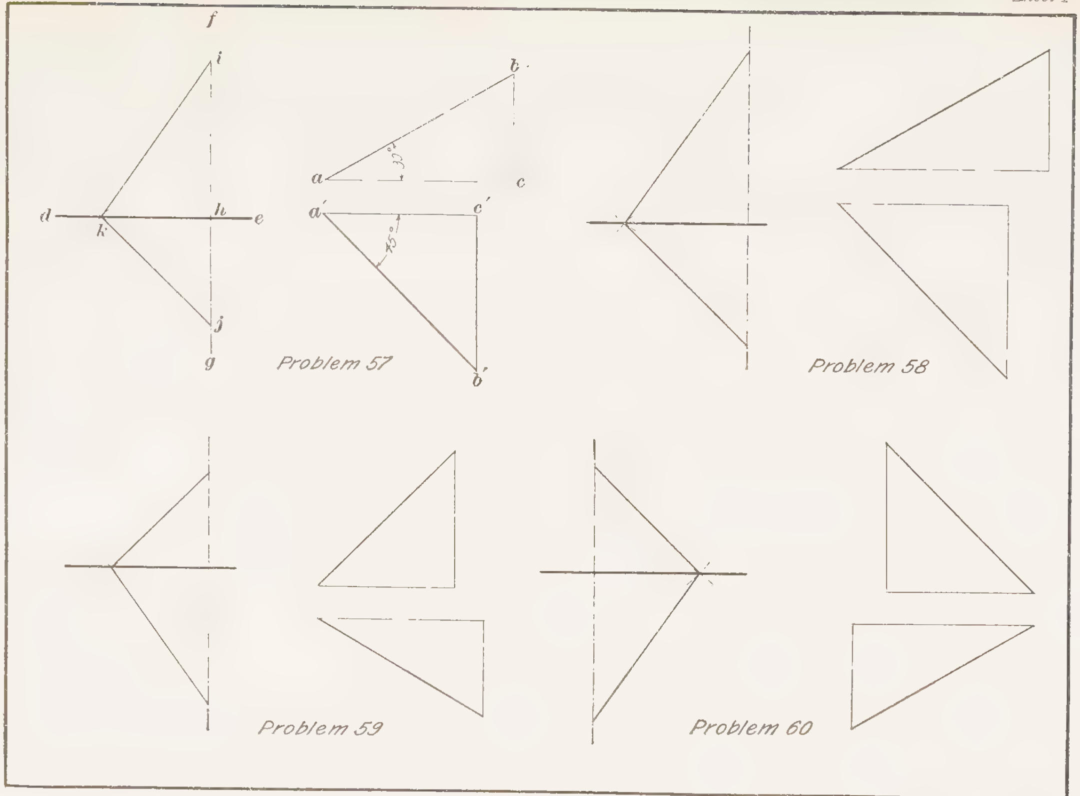
the front plane, as shown in Fig. 39, makes an angle of 30° with the vertical axis, and its projection on the front plane makes an angle of 45° with that axis. The projection in the front plane is $2\frac{15}{32}$ inches long; the upper end of the line is $2\frac{1}{16}$ inches from the side plane and $1\frac{21}{32}$ inches from the front plane. Find on the front plane the true length of the line, using the method described in Art. **17.**

Locate the vertical axis $2\frac{7}{8}$ inches from the right border line and the projections of the upper end of the line $3\frac{1}{4}$ inches from the lower border line.

Exercise V

Practical Projection, Part 2

Sheet I



Date

Name of Student, Class Letters, and Number

EXERCISE V

19. Finding Projections of Lines When Angles With Principal Planes Are Given.—Exercise V consists of two sheets, each of which has four problems relating to finding the projections of a line, inclined to the three principal planes, when the length of the line and the angles it makes with two of the principal planes are given. The process is the opposite of finding the true length of a line inclined to the three principal planes, as consideration of Fig. 40 will show. Let $a\,b$ be the line, and let two principal planes pass through one end of the line, as shown. Let $a\,b'$ and $a\,b''$ be the projections of the line $a\,b$ and let $a\,b''\,b_1$ be the auxiliary plane $a\,b\,b''$ turned on its horizontal trace $a\,b''$; let $a\,b'\,b_2$ be the auxiliary plane $a\,b'\,b$ turned on its front trace $a\,b'$. Then, as previously stated, the angle d is the angle the line makes with the plane on which the angle d was drawn, and the angle e is the angle the line makes with the other principal plane. Now, the length of the side $b_1\,b''$ of the triangle $a\,b''\,b_1 = b''\,b = c\,b'$, and the length of the side $b_2\,b'$ of the triangle $a\,b'\,b_2 = b'\,b = c\,b''$. Since projectors are perpendicular to planes, and projection lines to axes, it follows that the four triangles $a\,b_2\,b'$, $a\,b'\,c$, $a\,c\,b''$, and $a\,b''\,b_1$ are right-angled triangles. Consider the triangle $a\,b''\,b_1$; in this triangle, the length of $a\,b_1$, the angle d, and the angle d' are known, the latter being 90°, or a right angle. Similarly, in the triangle $a\,b_2\,b'$, the length of $a\,b_2$, the angle e, and the angle e' are known, the latter being 90°. Since three elements of each triangle are known, these triangles can be constructed, and when this is done the sides $a\,b'$ and $a\,b''$ give the length of the projections of $a\,b$ on the two planes. The inclination of each projection in reference to the axis is given if the two triangles $a\,c\,b''$ and $a\,c\,b'$ are constructed. To construct these, the following three elements are known for each: the length of two sides and the one angle. Thus, in the triangle $a\,c\,b''$ the length of the hypotenuse $a\,b''$ is known; it is also known that the length of the side $c\,b'' = b_2\,b'$, and that the angle the side $c\,b'$ makes with $a\,c$ is 90°. Similarly, in the

triangle $a\,c\,b'$, the length of the hypotenuse $a\,b'$ is known; the length of the side $c\,b'$ is known to be equal to $b''\,b_1$, and the angle between the lines $a\,c$ and $c\,b'$ is known to be 90°.

From the explanation just given, it will be obvious that by first constructing two right-angled triangles having for their hypotenuse the given length of the line and for one angle the given inclination to the principal planes, the necessary elements are obtained that will permit construction of two other right-angled triangles, either directly on the axes of two principal planes, or on projections of an axis of auxiliary planes parallel to the two principal planes. In these last two

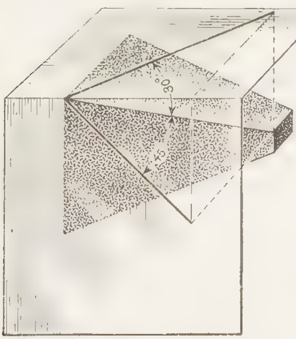


FIG. 41

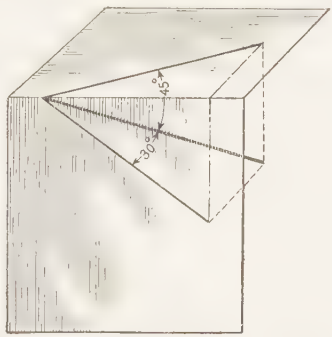


FIG. 42

triangles the hypotenuse of each is a projection of the given line.

To prevent overlapping of the solutions of Problems 57 to 64, inclusive, it is suggested that Sheets I and II of Exercise V be divided into four equal rectangular spaces by two pencil lines drawn midway between, and parallel to, the border lines. Each solution should then be kept in its own space.

20. PROBLEM 57. Sheet I.—As shown in Fig. 41, one end of a straight edge terminates on the horizontal axis. The edge makes an angle of 45° with the front plane, of 30° with the horizontal plane, and is $2\frac{1}{4}$ inches long. Show its projections on the front and horizontal planes.

SOLUTION.—Referring to the reduced copy of Sheet I, Exercise V, in any convenient position draw the straight

lines $a\,b$ and $a'\,b'$, each $2\frac{1}{4}$ inches long. Draw a line through the point a at an angle of 30° with the line $a\,b$, and through the point a' at an angle of 45° with $a'\,b'$. From the points b and b' draw perpendiculars $b\,c$ and $b'\,c'$ to the lines drawn through a and a', thus obtaining the triangles $a\,b\,c$ and $a'\,b'\,c'$. In the triangle $a\,b\,c$, the side $a\,c$ gives the length of the projection on the horizontal plane, and the length of the side $b\,c$ gives the distance that the one end of the given edge is below the horizontal plane. Likewise, in the triangle $a'\,b'\,c'$, the side $a'\,c'$ gives the length of the projection on the front plane, and the length of the side $b'\,c'$ gives the distance the one end of the edge is from the front plane.

Having drawn a line $d\,e$ to represent the horizontal axis, draw a projection line $f\,g$ and on it lay off $h\,i = b'\,c'$ and

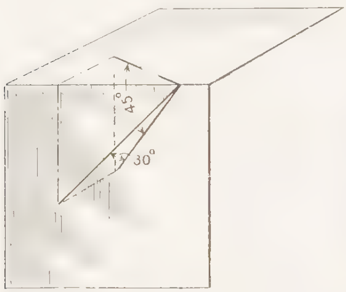


Fig. 43

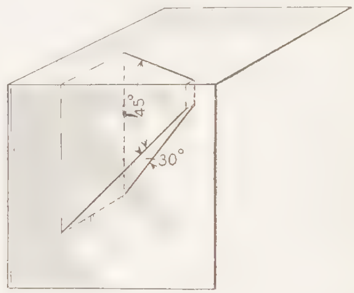


Fig. 44

$h\,j = b\,c$. With the point i as a center and $a\,c$ as a radius, or with j as a center and $a'\,c'$ as a radius, describe an arc intersecting the horizontal axis at k. Join the intersection k with i and j by straight lines; the line $k\,i$ is the horizontal projection and the line $k\,j$ the front projection of the given edge.

When solving problems similar to the one just given, it is well to bear in mind that after the two triangles have been constructed the length of the side adjacent the right angle and adjoining the given angle with a plane, as $a\,c$ and $a'\,c'$, is the length of the projection of the line *on the same plane.*

Problem 58.—A straight line $2\frac{1}{2}$ inches long terminates on the horizontal axis, being inclined as shown in Fig. 41. It

makes an angle of 30° with the horizontal plane and of 45° with the front plane. Show its projections on the two planes named.

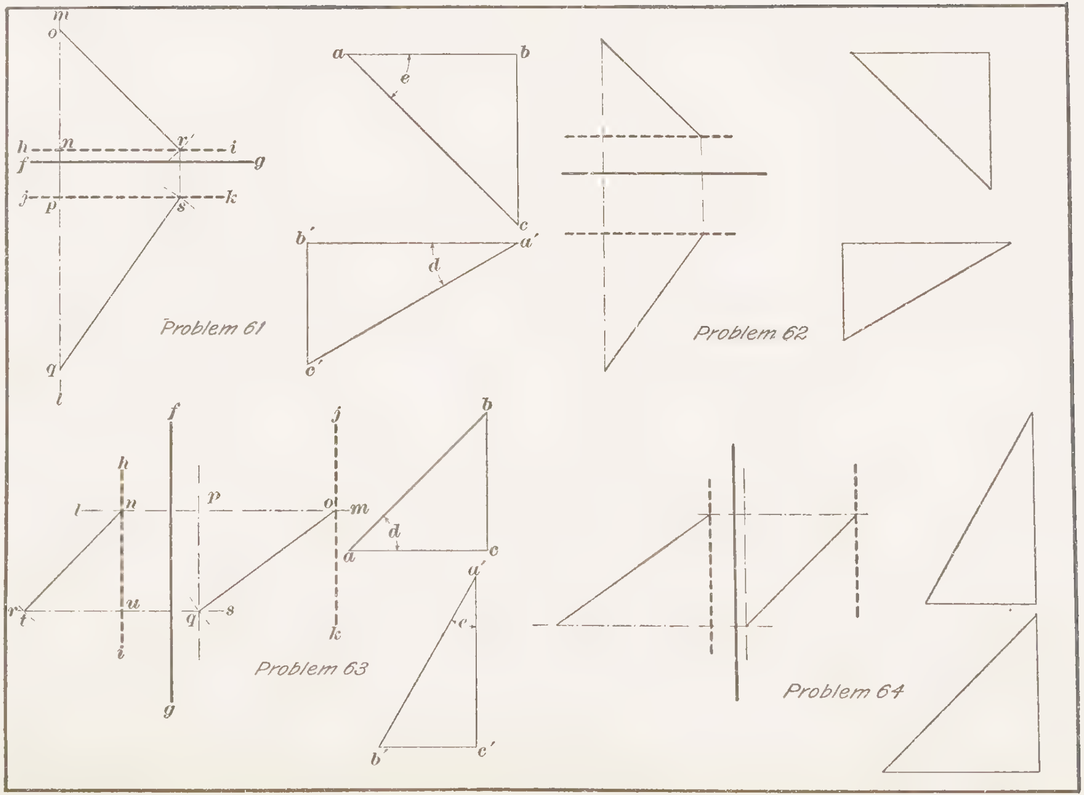
PROBLEM 59.—A straight line 2 inches long has one end on the horizontal axis, and, as shown in Fig. 42, it makes an angle of 45° with the horizontal plane and of 30° with the front plane. Show its projections on the two planes named.

PROBLEM 60.—As shown in Fig. 43, one end of a straight line $2\frac{3}{16}$ inches in length rests on the horizontal axis. The line makes an angle of 45° with the horizontal plane and of 30° with the front plane, in the direction shown in Fig. 43. Show its projections on the two planes named.

21. PROBLEM 61. Sheet II.—As shown in Fig. 44, a straight line $2\frac{1}{2}$ inches long makes an angle of 45° with the horizontal plane and of 30° with the front plane, in the directions indicated. The upper end of the line is $\frac{1}{8}$ inch from the front plane and $\frac{3}{8}$ inch from the horizontal plane. Show the projections of the line on the front and horizontal planes.

SOLUTION.—Referring to the reduced copy of Sheet II, Exercise V, draw the two right-angled triangles $a\,b\,c$ and $a'\,b'\,c'$, having the hypotenuses $a\,c$ and $a'\,c' = 2\frac{1}{2}$ inches, and the angles d and $e = 30°$ and 45°, respectively.

Draw a straight line $f\,g$ to represent the horizontal axis, and parallel thereto and at distances of $\frac{1}{8}$ inch and $\frac{3}{8}$ inch, respectively, draw the lines $h\,i$ and $j\,k$, which are two projections of the horizontal axis of two auxiliary planes parallel to the two principal planes. These two planes are so taken that the upper end of the given line rests on their horizontal axis, and, consequently, one end of each projection of the given line will rest on each projection of the axis of the two auxiliary planes. Next, in any convenient place, draw a projection line $l\,m$ and on it lay off the distance $n\,o = b'\,c'$, and $p\,q = b\,c$. With o as a center and $a\,b$ as a radius, and with q as a center and $a'\,b'$ as a radius, describe arcs intersecting $h\,i$ in r and $j\,k$ in s; join o and r and q and s by


Problem 61
Problem 62
Problem 63
Problem 64

straight lines, which are the required projections. As a test of the accuracy of the work, draw a projection line through *r* or *s*; if the work has been accurately done, this projection line will pass through the points *s* or *r*.

PROBLEM 62.—A straight line 2 inches long makes an angle of 45° with the horizontal plane and of 30° with the front plane, in the directions shown in Fig. 44. The upper end of the line is $\frac{3}{8}$ inch from the front plane and $\frac{5}{8}$ inch from the horizontal plane; show the projections of the line on these two planes.

PROBLEM 63.—A straight line 2 inches long makes an angle of 45° with the front plane and of 30° with the side plane, in the directions shown in Fig. 45. The upper end of

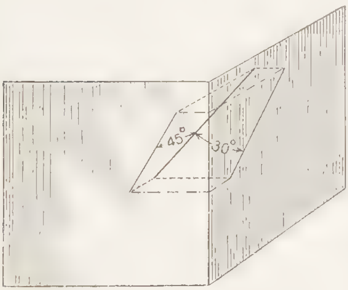


FIG. 45

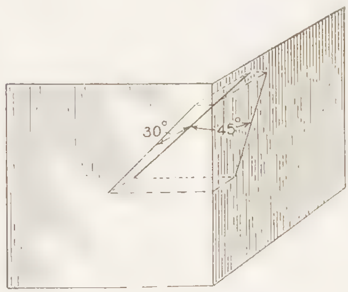


FIG. 46

the line is $1\frac{11}{16}$ inches from the front plane and $\frac{1}{2}$ inch from the side plane. Show its projections on the two planes named, the side plane being at the right of the front plane.

SOLUTION.—Referring to the reduced copy of Sheet II, Exercise V, draw the right-angled triangles *a b c* and *a′ b′c′* in any convenient position, making their hypotenuses 2 inches long, and the angles *d* and *e* 45° and 30°, respectively. Draw the vertical axis *f g*, and parallel thereto and at distances of $\frac{1}{2}$ inch and $1\frac{11}{16}$ inches from it, the lines *h i* and *j k*. Draw a projection line *l m*; its intersections *n* and *o* with the lines *h i* and *j k* fix the position of the projection of the upper end of the line on the two planes. On the line *l m* lay off *o p* = *b c*,

and through the point p draw a straight line perpendicular to the projection line $l\,m$, and hence parallel to the vertical axis. Then, with o as a center and $a'\,c'$ as a radius, describe an arc intersecting at q the line just drawn. Join q and o by a straight line, which will be the projection of the given line on the side plane. Through q draw a projection line $r\,s$; with n as a center and $a\,c$ as a radius, describe an arc intersecting at t the line just drawn. Join t and n by a straight line, which will be the required projection on the front plane. As a test of the accuracy of the work see whether $t\,u = b'\,c'$; these two distances must be equal.

PROBLEM 64.—A straight line $2\frac{1}{4}$ inches long is inclined 45° to the side plane and 30° to the front plane, in the directions shown in Fig. 46. The upper end of the line is $1\frac{1}{4}$ inches from the front plane and $\frac{1}{4}$ inch from the side plane. Show its projections on the two planes named, the side plane being at the right of the front plane.

PRACTICAL PROJECTION
(PART 3)

PROJECTION OF SURFACES

PROJECTION OF SURFACES ON PRINCIPAL PLANES

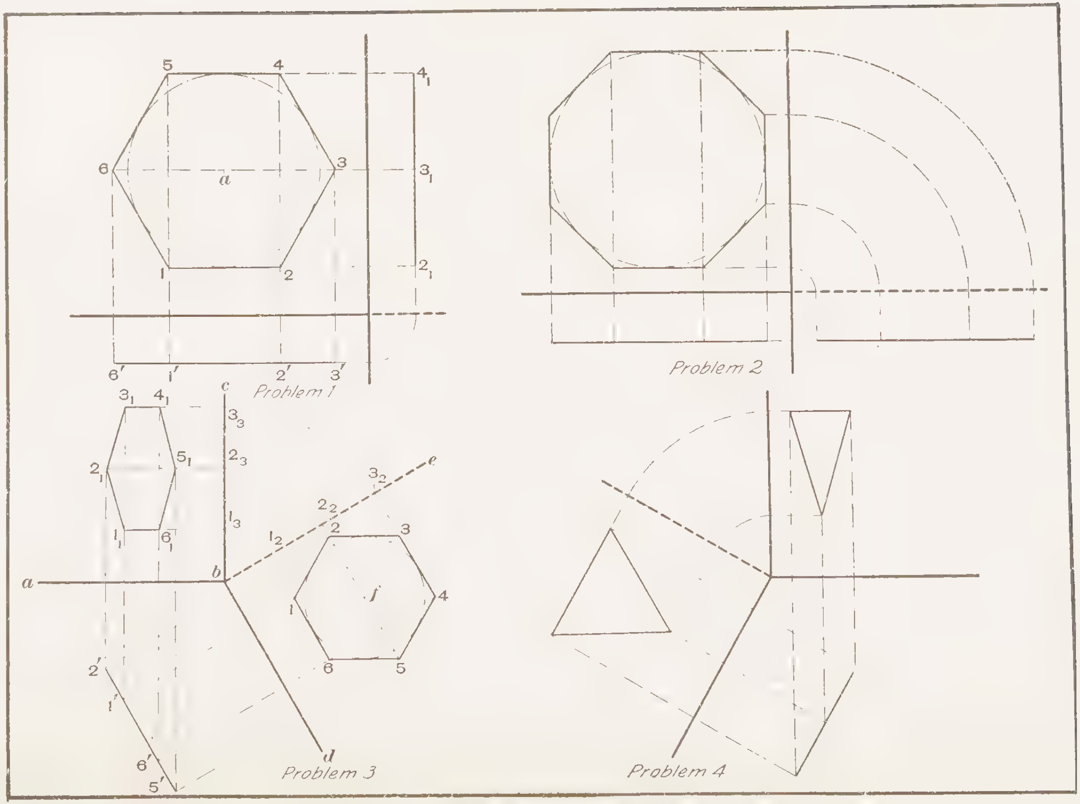
EXERCISE I

1. Exercise I consists of four sheets, which contain, in all, twelve problems relating to the projection of plane surfaces of various outlines and occupying various positions in reference to the principal planes.

PROBLEM 1. Sheet I.—The one end of a regular hexagonal prism, circumscribing a circle having a diameter of 2 inches, is in a plane parallel to the horizontal plane and $\frac{1}{2}$ inch below it. One side of the prism, as shown in Fig. 1, is parallel to the front plane. The center of the circle is $1\frac{1}{2}$ inches from the side and front planes. The side plane, being at the right of the horizontal plane, shows the projections of the hexagonal surface on the three principal planes.

SOLUTION.—Referring to the reduced copy of Sheet I, Exercise I, draw the horizontal axis about $3\frac{1}{8}$ inches from the upper border line; draw the vertical and side axes about $3\frac{3}{4}$ inches from the left border line. Locate the center *a* $1\frac{1}{2}$ inches from the horizontal and side axes. Draw a circle 2 inches in diameter with *a* as a center and construct the hexagon *1–2–3–4–5–6*, making the side *1–2* parallel to the

Exercise I — Practical Projection, Part 3 — Sheet I



horizontal axis. Project the points *1* to *6*, that is, the corners, into the front and side planes, and draw the front projection $6'-1'-2'-3'$ and the side projection $2_1-3_1-4_1$ at a distance of $\frac{1}{2}$ inch from the horizontal and side axes. Because the hexagonal plane surface is parallel to the horizontal plane, it is perpendicular to the front and side planes, and hence the front and side projections will be straight lines.

If the hexagon has been accurately drawn, the projection lines drawn from *5*, *4*, and *6* will pass through *1*, *2*, and *3*, respectively. In the front projection the point $1'$ is the projection of the points *1* and *5*; likewise, the point $2'$ is the projection of the points *2* and *4*. In the side projection, the point 2_1 is the projection of the points *1* and *2*; the point 3_1

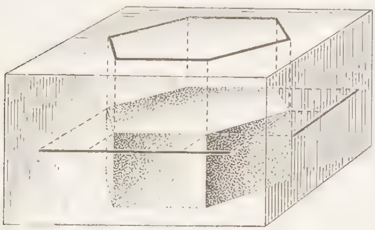


FIG. 1

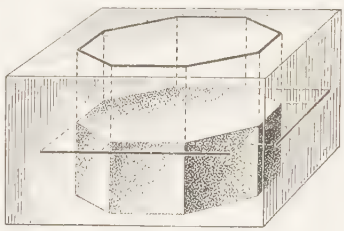


FIG. 2

is the projection of the points *6* and *3*; the point 4_1 is the projection of the points *5* and *4*.

PROBLEM 2.—One end of a regular octagonal prism, circumscribing a circle $2\frac{1}{4}$ inches in diameter, is in a plane parallel to the horizontal plane, and, as shown in Fig. 2, one of the sides of the prism is parallel to the front plane. The upper end of the prism is $\frac{1}{2}$ inch from the horizontal plane, and its center line is $1\frac{3}{8}$ inches from the front and side planes. Show the projections of the upper end on the three planes, the side plane being at the right of the front plane.

Locate the horizontal axis $2\frac{15}{16}$ inches from the upper border line and the vertical and side axes $2\frac{13}{16}$ inches from the right border line.

PROBLEM 3.—One end of a regular hexagonal prism, circumscribing a circle having a diameter of $1\frac{1}{4}$ inches, is in

a plane perpendicular to the front plane and at an angle of 60°, measured as shown in Fig. 3, with the horizontal plane. For the sake of clearness, the angle given is shown between an auxiliary plane parallel to the plane of the given surface and the horizontal plane. One side of the prism is parallel to the front plane; the center line of the prism is $1\frac{3}{16}$ inches from the front plane. Show the projections of the hexagonal surface on the horizontal and front planes.

SOLUTION.—Refer to the reduced copy of Sheet I, Exercise I, and also to Fig. 3. As an inspection of Fig. 3 will show, nearly all the lines of the hexagonal surface will show foreshortened in the horizontal and front projections; the length and position of these lines must be obtained from a full view drawn on an auxiliary plane parallel to the plane containing the hexagonal surface. This auxiliary plane may be turned either on its horizontal trace or on its front trace to the plane of the drawing, as may be most convenient; in the solution here presented, the auxiliary plane has been turned on its front trace.

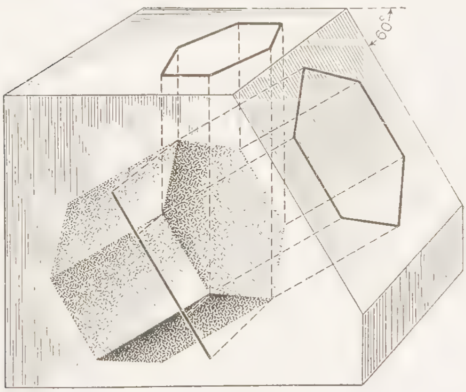


FIG. 3

Since projections on the horizontal and front planes are called for, draw a line $a\,b$ to represent the horizontal axis. This line may be drawn about $2\frac{3}{16}$ inches from the lower border line, locating its end b about $2\frac{1}{4}$ inches from the left border line. At b draw the horizontal trace $b\,c$, which is perpendicular to $a\,b$; also draw the front trace $b\,d$ at an angle of 120° with $a\,b$. Draw the revolved horizontal trace $b\,e$, which is perpendicular to the front trace, since the auxiliary plane is perpendicular to the front plane. Locate the center f

of the circle inscribed in the hexagon $1\frac{3}{16}$ inches from the front trace and any convenient distance, say $\frac{7}{8}$ inch, from the revolved horizontal trace. With the point *f* as a center, draw a circle $1\frac{1}{4}$ inches in diameter and around it draw the hexagon *1–2–3–4–5–6*, taking care to make the side *1–6* parallel to the front trace, as this side is parallel to the front plane. From the corners *1* to *6* draw projection lines, which are perpendicular to the front trace, a sufficient distance into the front plane, and at any convenient distance from the front trace, say $1\frac{1}{4}$ inches, draw the straight line $2'$–$1'$–$6'$-$5'$ parallel to the front trace; this line is the front projection of the hexagonal surface. It will be understood that the point $1'$ represents the projection of the corners *1* and *3*, and the point $6'$ of the corners *6* and *4*. From the points $2'$, $1'$, $6'$, $5'$ draw projection lines a sufficient distance into the horizontal plane. From the corners *1* to *6* draw projection lines to the revolved horizontal trace *b e*, intersecting this trace at 1_2, 2_2, and 3_2. It will be understood that the projection lines from the corners *1* and *6* coincide, and likewise those drawn from the corners *2* and *5*, as well as those drawn from the corners *3* and *4*. With *b* as a center and $b\,1_2$, $b\,2_2$, and $b\,3_2$ as radii, describe arcs intersecting the horizontal trace *b c* at 1_3, 2_3, and 3_3, and from these points of intersection draw projection lines, which are parallel to the horizontal axis, to intersect the projection lines drawn from the front projection into the horizontal plane. The intersections 1_1 to 6_1 are the projections on the horizontal plane of the corners *1* to *6*. Join the intersections 1_1 to 6_1 by straight lines; the resulting figure is the required horizontal projection of the hexagonal surface.

The solution of this problem should make it clear that the projection of plane surfaces resolves itself into the successive projection of points on their boundary lines. In case of plane surfaces presenting easily recognizable corners, it is the usual practice, on account of its convenience, to project the corners.

PROBLEM 4.—Each end of a triangular prism forms an equilateral triangle having sides $1\frac{1}{4}$ inches long; the one end

is situated in a plane perpendicular to the front plane and at an angle of 60° with the horizontal plane, as indicated in Fig. 4. One side of the end is parallel to, and $1\frac{11}{16}$ inches from, the front plane. Show the front and horizontal projections of the one end. The auxiliary plane is to be at the left and turned on its front trace.

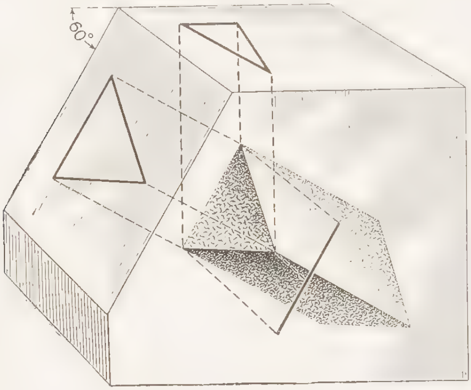


Fig. 4

Locate the horizontal axis $2\frac{3}{16}$ inches from the lower border line, and the horizontal trace $3\frac{1}{8}$ inches from the right border line.

2. Problem 5. Sheet II.—One end of a cylinder having a diameter of 2 inches is located in a plane perpendicular to the front plane and inclined 60° to the horizontal plane, as indicated in Fig. 5. The center of the one end of the cylinder is $1\frac{3}{8}$ inches from the front plane and $2\frac{1}{4}$ inches from the horizontal plane. The ends of the cylinder are at right angles to the axis. Show the horizontal and front projections of the one end of the cylinder.

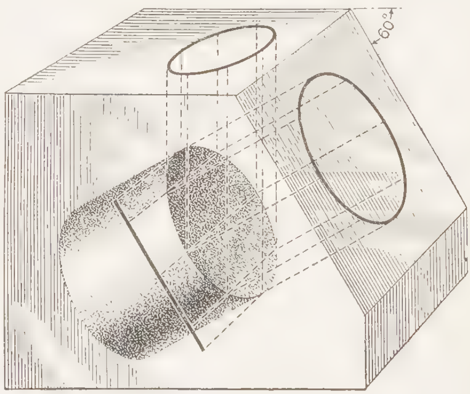
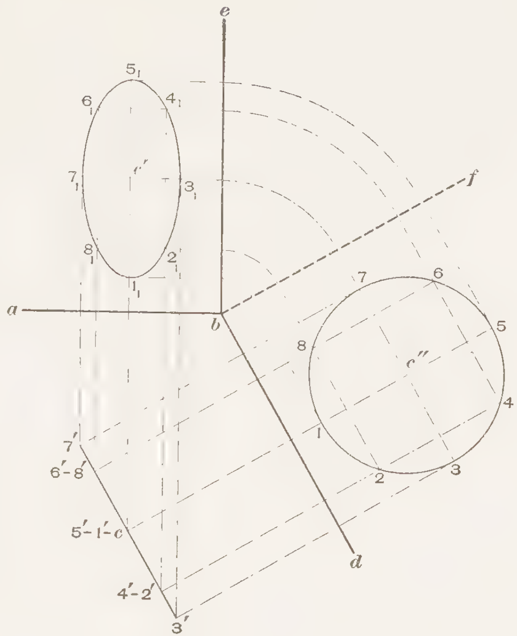
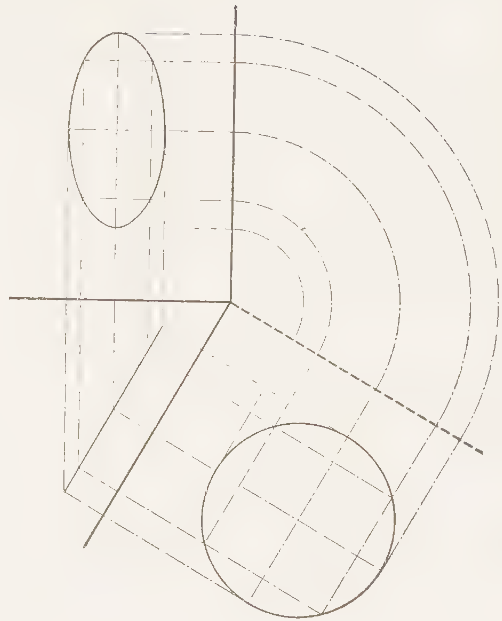


Fig. 5

Solution.—Referring to the reduced copy of Sheet II, Exercise I, draw the horizontal axis $a\,b$ 4 inches from the upper border line, and, in any convenient



Problem 5



Problem 6

Date

Name of Student, Class Letters, and Number

location, say $1\frac{7}{16}$ inches from the left border line, a projection line. On this projection line locate the centers c and c' of the end of the cylinder. At any convenient distance from the center c, say $1\frac{15}{16}$ inches, draw the front trace $b\ d$; also draw the horizontal trace $b\ e$, which, since the auxiliary plane on which the full view is to be drawn is perpendicular to the front plane, is perpendicular to the horizontal axis. The auxiliary plane may be turned on its horizontal or its front trace to the level of the drawing, just as may be most convenient; if the plane is turned on its front trace, as done here, draw the revolved horizontal trace $b\ f$. Now locate the projection c'' of the center of the end on the auxiliary plane and draw the full view of the end, which is a circle.

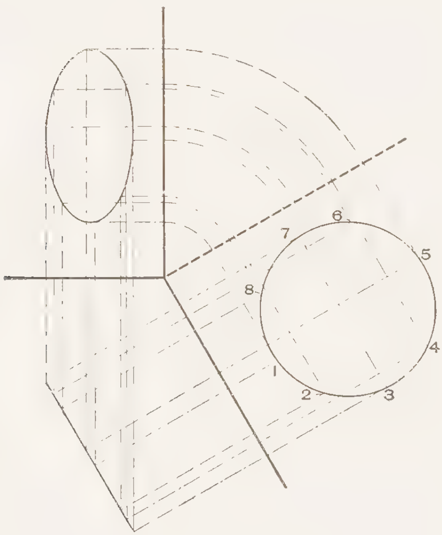


Fig. 6

A circle, as well as any other curvilinear figure, can be projected only by projecting a number of arbitrarily chosen points on the circumference. The projections of these points, whose number and location is entirely a matter of choice based on judgment and experience, are then shown on the different planes, and are joined by a curved line.

In many cases, especially when circles are to be projected, it is advisable to choose a number of points that is divisible by 4, to place them equidistant, and to arrange their location so that one projection line will serve to project the projection of two points. This has been done in the solution of Problem 5 shown on the reduced copy of Sheet II, Exercise I. Starting at the intersection *1* of the line $c\ c''$ with the circumference of the circle, this has been divided into eight equal parts;

these projections *1* to *8* are projected into the front plane by the projection lines *8–8′*, *7–7′*, etc. Through the center *c* draw the line *7′–3′* parallel to the front trace *b d*; this line is the front projection of the circle. Now project the projections *1′* to *8′* and *1* to *8* into the horizontal plane to obtain the projections 1_1 to 8_1; using an irregular curve, draw a line through the projections 1_1–2_1, etc. to represent the horizontal projection of the circle.

In order to show how, by a judicious selection of the number and location of points on the circumference, the number of projection lines can be reduced, Fig. 6 is presented. In this solution the projections *1* to *8* of the points were selected at random and consequently no two projections lie on a single projection line. Hence, as will be seen by contrasting the solution presented in Fig. 6 with that given on the reduced copy of Sheet II, Exercise I, more projection lines must be used to obtain the same result.

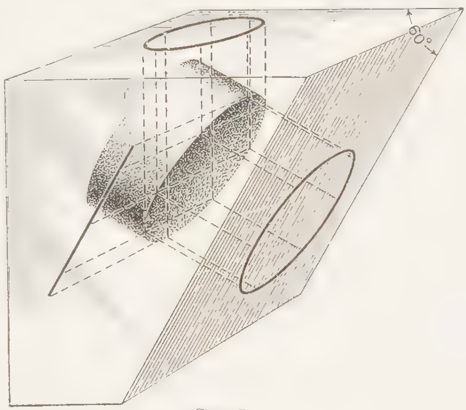
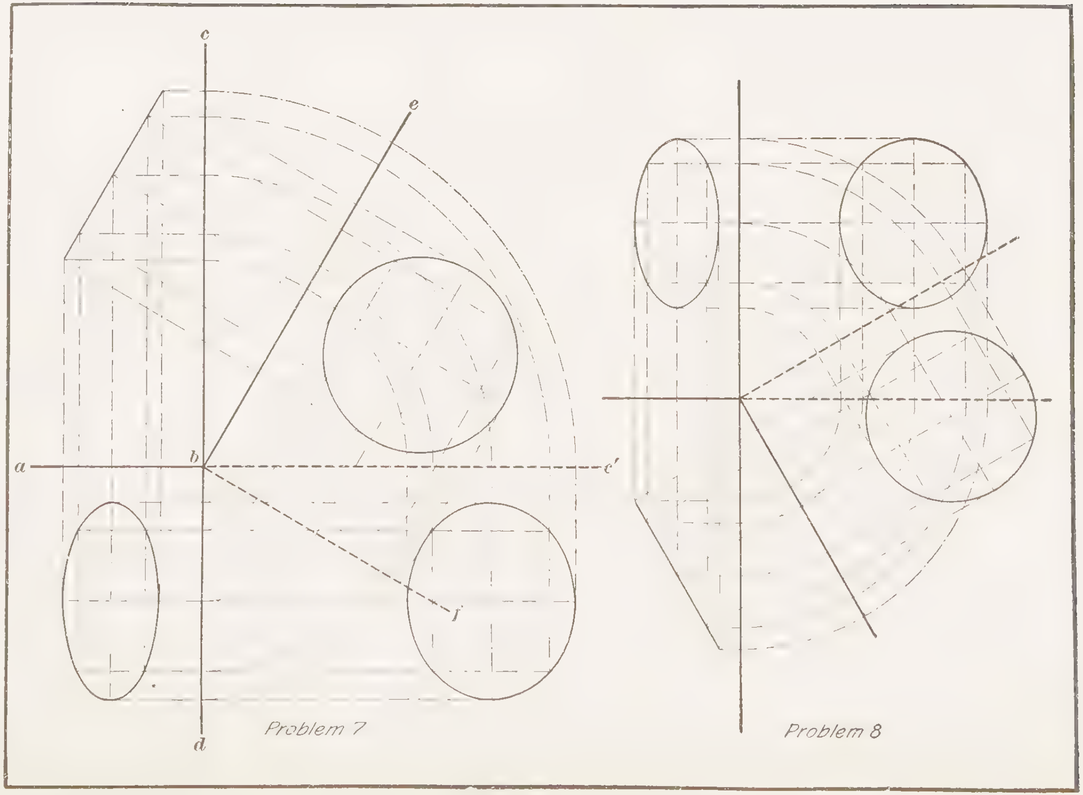


FIG. 7

PROBLEM 6.—A circular plane surface, the one end of a cylinder 2 inches in diameter, as indicated in Fig. 7, is situated in a plane perpendicular to the front plane and at an angle of 60° with the horizontal plane. The center of the surface is $1\frac{3}{4}$ inches from the front plane and $1\frac{1}{8}$ inches from the horizontal plane. Show the full view on the auxiliary plane turned on its front trace, and show the front and horizontal projections.

Locate the horizontal axis 4 inches from the upper border line and the horizontal trace $2\frac{7}{8}$ inches from the right border line.

Exercise I — Practical Projection, Part 3 — Sheet III



Date

Name of Student, Class Letters, and Number

3. PROBLEM 7. Sheet III.—A circular plane surface 2 inches in diameter is situated in a plane perpendicular to the horizontal plane and making an angle of 30° with the side plane, measured as shown in Fig. 8. The center of the surface is 3 inches from the front plane, $1\frac{3}{8}$ inches from the horizontal plane, and $\frac{15}{16}$ inch from the side plane. Show the front view, top view, and side view of the surface, the side plane being at the right of the front plane. Turn the auxiliary plane on its horizontal trace.

SOLUTION.—Referring to the reduced copy of Sheet III, Exercise I, draw the horizontal axis *a b* in any convenient

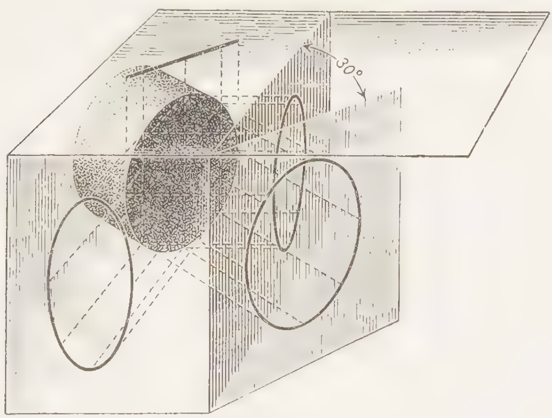


FIG. 8

location, say $3\frac{1}{4}$ inches from the lower border line. In any convenient location, say 2 inches from the left border line, draw the vertical axis *b d* and the side axis *b c*. Draw the horizontal trace *b e* at an angle of 30° with the side axis, and draw the revolved front trace *b f* perpendicular to *b e*. Also draw the revolved side axis *b c'*. Locate the center of the circle on the horizontal and front planes, and project it to the auxiliary plane, where the full view is drawn. Choose points on the circumference of the circle on the auxiliary plane and project these points into the three principal planes; through their projection draw the outlines of the several views.

In the solution presented, the circle has been divided into

eight equal parts; the student may use this or any other number of points.

PROBLEM 8.—A circular surface having a diameter of $1\frac{3}{4}$ inches is in a plane perpendicular to the front plane and making an angle of 30°, measured as shown in Fig. 9, with the side plane. The center of the circle is $1\frac{13}{16}$ inches from the horizontal and front planes, and $\frac{21}{32}$ inch from the side plane. Show the projections of the surface on the front, side, and horizontal planes, the side plane being at the right of the horizontal plane.

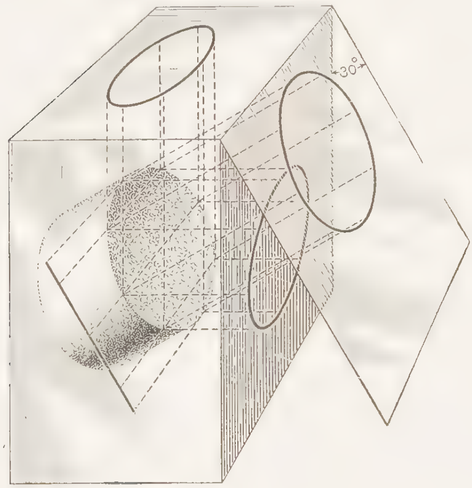


FIG. 9

Locate the horizontal axis 4 inches from the upper border line and the vertical and side axes $3\frac{7}{16}$ inches from the right border line.

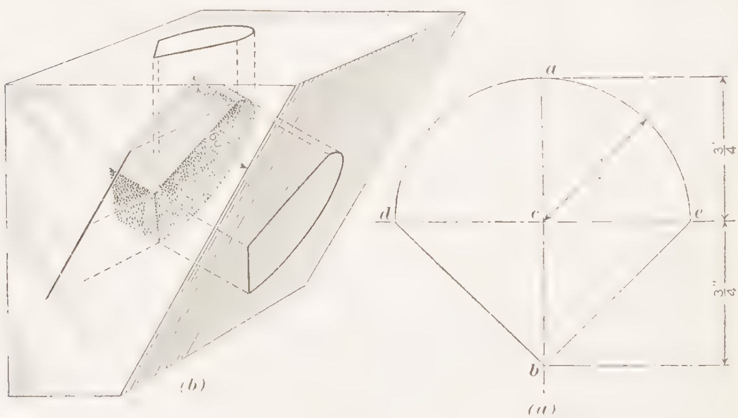
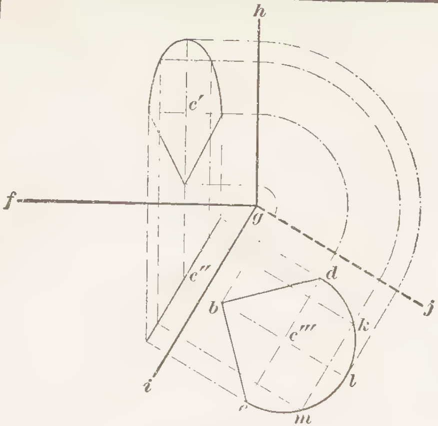
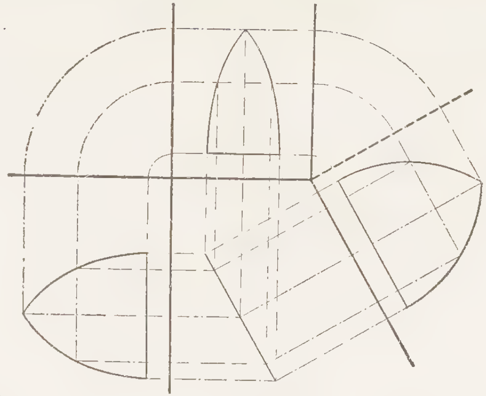


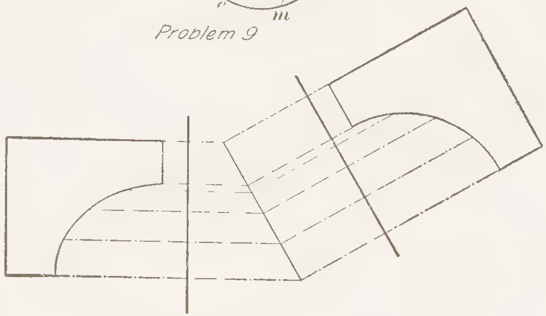
FIG. 10



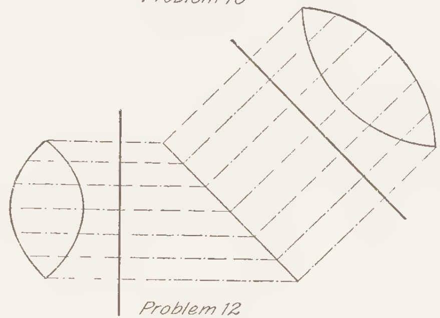
Problem 9



Problem 10



Problem 11



Problem 12

Date

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4. Problem 9. Sheet IV.—The plane figure shown in Fig. 10 (*a*) is located on a plane perpendicular to the front plane and making an angle of 60°, measured as shown in Fig. 10 (*b*), with the horizontal plane. The center line $a\,b$, Fig. 10 (*a*), is parallel to the horizontal plane. The point of intersection c of the center line $d\,e$ with the center line $a\,b$ is $\frac{15}{16}$ inch from the front plane and $\frac{25}{32}$ inch from the horizontal plane. Show the horizontal and front projections of the figure.

Solution.—Referring to the reduced copy of Sheet IV, Exercise I, in any convenient location, say $2\frac{1}{8}$ inches from the upper border line, draw the horizontal axis $f\,g$. At any convenient distance from the left border line, say $2\frac{11}{16}$ inches, draw the horizontal trace $g\,h$, which is perpendicular to the horizontal axis, since the auxiliary plane is perpendicular to the front plane. Draw the front trace $g\,i$ at an angle of 60° with the horizontal axis. The full view may be drawn on the auxiliary plane turned either on its horizontal trace or on its front trace. In the solution presented, the auxiliary plane was turned on its front trace; hence, draw the revolved horizontal trace $g\,j$, which is perpendicular to the front trace. At any convenient distance from the horizontal trace, say $\frac{3}{4}$ inch, draw a projection line extending sufficiently into the horizontal and front planes and on it locate the projections c' and c'' of the intersection c, Fig. 10 (*a*), $\frac{15}{16}$ inch above and $\frac{25}{32}$ inch below the horizontal axis. Through the projection c'' draw a projection line into the auxiliary plane; this projection line will represent on the auxiliary plane the center line $a\,b$, Fig. 10 (*a*), which, as stated in the problem, is parallel to the horizontal plane and perpendicular to the front plane, and hence its projection on the auxiliary plane is perpendicular to its front trace. On the auxiliary plane now locate the projection c''', and construct the full view from the dimensions given in Fig. 10 (*a*). The sharp corners b, d, and e are convenient points to project, as their projections give at once the length and position of the projections of the straight lines $b\,d$ and $b\,e$. The arc $d\,e$ must be projected by projecting

points on its projection in the full view; in the solution presented, the arc is divided into four equal parts, thus giving

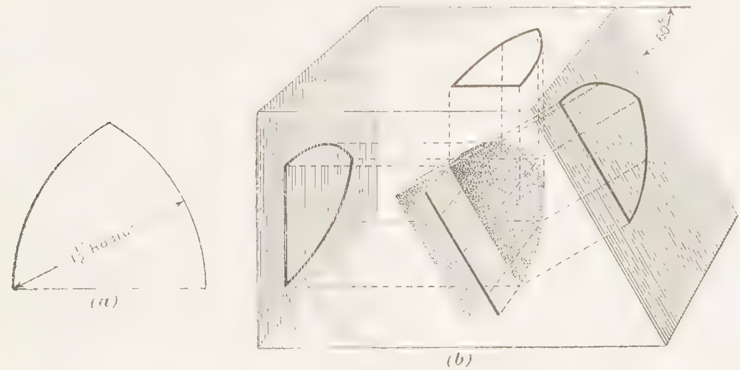


Fig. 11

three points k, l, and m, additional to the corners d and e. Project the points b, d, k, l, m, and e into the horizontal and front planes, and through their projections draw the projected outline of the figure.

Problem 10.—The plane figure shown in Fig. 11 (a) is in a plane perpendicular to the front plane and making an angle of 60° with the horizontal plane, as indicated in Fig. 11(b).

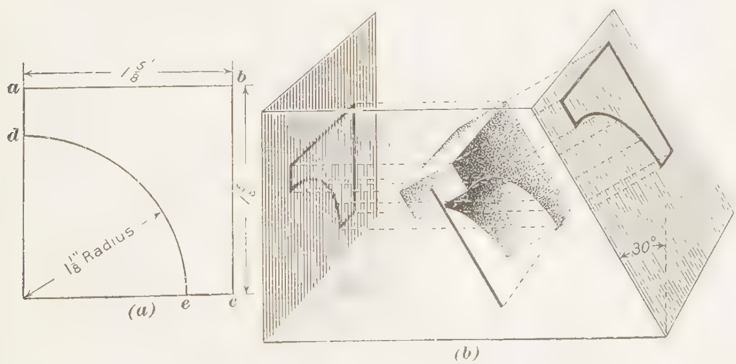


Fig. 12

The straight edge of the figure is parallel to the front plane and $\frac{1}{4}$ inch from it; the highest corner is $\frac{25}{32}$ inch from the

horizontal plane. Show the top, side, and front views, the side plane being at the left of the front plane.

Locate the horizontal axis $2\frac{1}{8}$ inches from the upper border line; locate the vertical and side axes 4 inches from the right border line; locate the horizontal trace $1\frac{7}{16}$ inches from the side axis; and turn the auxiliary plane on its front trace.

PROBLEM 11.—The plane figure shown in Fig. 12 (*a*) is in a plane perpendicular to the front plane and inclined 30° to the side plane, which is at the left of the front plane, as indicated in Fig. 12 (*b*), which also shows the direction in which the auxiliary plane inclines toward the side plane. The straight edge *a b* of the figure is perpendicular to the

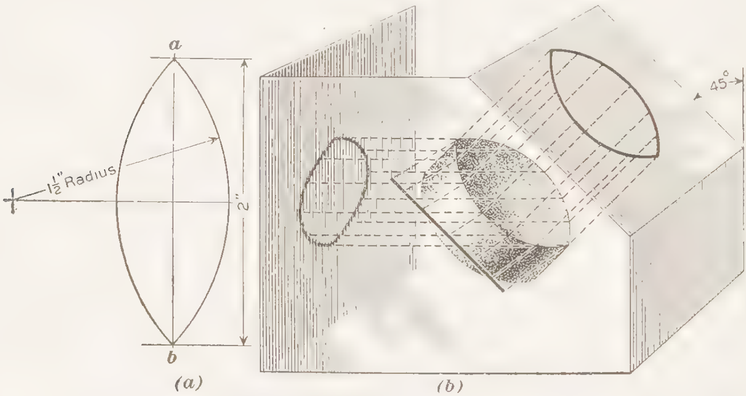


FIG. 13

front plane, and the straight edge *b c* is parallel to that plane. The straight edge *a d* is also parallel to the front plane and $\frac{1}{4}$ inch from it. The corner *a* is $\frac{5}{16}$ inch from the side plane. Show the front and side views.

Locate the vertical axis $2\frac{1}{4}$ inches from the left border line; locate the front projection of the corner *a*, Fig. 12 (*a*), $2\frac{3}{8}$ inches from the lower border line, and locate the front trace $1\frac{1}{32}$ inches from the front projection of the corner *a*. Turn the auxiliary plane on its front trace. It is suggested that the arc *d e*, Fig. 12 (*a*), be divided into four parts, and that the projections of the various points be located on the side plane by measurement.

PROBLEM 12.—The plane figure shown in Fig. 13 (*a*) is in a plane perpendicular to the front plane and making an angle of 45° with the side plane, the inclination being in the direction shown in Fig. 13 (*b*). The center line *a b*, Fig. 13 (*a*), is parallel to the front plane; the upper corner *a* is $\frac{3}{4}$ inch from the front plane and $\frac{7}{16}$ inch from the side plane. Show the front and side views of the figure, the side plane being at the left of the front plane and the auxiliary plane being turned on its front trace.

Locate the vertical axis $3\frac{5}{8}$ inches from the right border line; locate the front trace $1\frac{1}{4}$ inches from the front projection of the corner *a*; and locate the front projection of the corner *a* about 2 inches above the lower border line. It is suggested that each arc of the figure be divided into six equal parts.

FINDING FULL VIEWS FROM PROJECTIONS ON PRINCIPAL PLANES

EXERCISE II

5. In practice, it is often necessary to obtain full views of plane surfaces that are either inclined to two of the principal planes and perpendicular to the third, or, more rarely, that are inclined to the three principal planes. In either case, the projection of the given surface on two of the principal planes must be given; from these the full view can be constructed.

There are three methods by which a full view may be obtained from two given projections of a plane surface.

In the first method, the traces of the plane containing the given plane surface are determined from the given projections, and the full view is drawn on the plane, or on an auxiliary plane parallel to that plane, of the given surface; the traces of this auxiliary plane obviously are parallel to the traces of the plane containing the given surface. The plane of the surface or the auxiliary plane is turned into the plane of the drawing around whichever trace is most convenient, and the full view is projected thereon from the given projections.

In the second method, the given surface is turned in space in one or more steps until it is in a plane parallel to one of the principal planes, and then the full view is drawn on that principal plane.

In the third method, the given plane surface is divided into a number of adjacent triangles. The true length of each line of each triangle is then determined to obtain a full view of each triangle. The full view of the given plane surface is finally constructed by assembling the different full views of the triangles.

Each of the three methods here briefly explained is mathematically exact, and hence the adoption of any one of them is a question of expediency. Generally speaking, the first and second methods are used in machine drawing; the third method is used, practically to the exclusion of the other two, by sheet-metal workers and boiler makers, as it enables them to lay out the required full view directly on the sheet or plate of metal, without first laying out a full view on the drawing and then transferring it to the sheet or plate.

Both the first and the second method will show the full view in true relation to the projections; the third method will produce a correct full view, but not in correct position in relation to the projections from which it was drawn.

6. As stated in Art. **5,** in the one method of finding the full view, the traces of the plane containing the surface are determined from the two given projections. The simplest and most frequent case arising in practice is that where the plane containing the given surface is inclined to two of the principal planes and is perpendicular to the third, one instance of which is presented in Fig. 14, where the given plane surface is in a plane inclined to the horizontal and front planes and is perpendicular to the side plane.

If the projections of the plane surface on the three principal planes are given, it can be determined at once by inspection whether or not the plane of the surface is perpendicular to one of the principal planes, for in that case one of the three projections must be a straight line. At the same time, the

projection showing as a straight line, as the side projection in Fig. 14, is also a part of the intersection of the plane containing the surface with the plane on which the projection shows as a straight line; in other words, the straight line representing the projection is also part of one trace of the plane containing the given surface.

When only two projections of a plane surface are given, it may be necessary to construct the third to determine whether the plane of the given surface is perpendicular to one principal plane. Thus, referring to Fig. 14, if only the horizontal and front projections *a b c d e* and *a′ b′ c′ d′ e′* of the surface *A B C D E* are given, it will be necessary to construct the side projection *c″ d″ e″* and note whether it is a straight line. On the other hand, if, in this particular case, the horizontal and side projections, or the front and side projections, had been given, inspection would have shown at once that the plane of the given surface was perpendicular to the side plane, since the side view is a straight line.

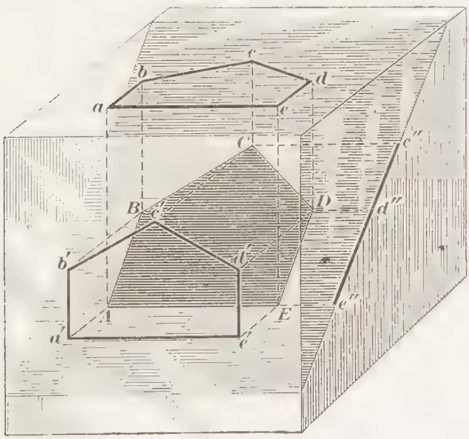
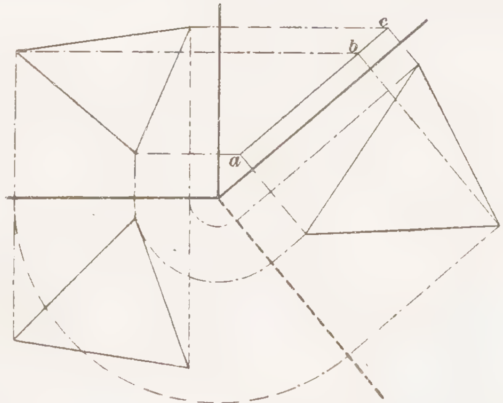


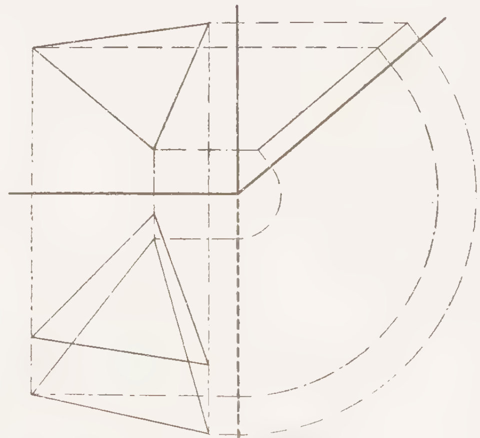
FIG. 14

It having been determined that the plane of the given inclined plane surface is perpendicular to one principal plane, its one trace coinciding with that projection showing as a straight line, the other two traces are known to be parallel to the axes of the two principal planes to which the plane of the given surface is inclined.

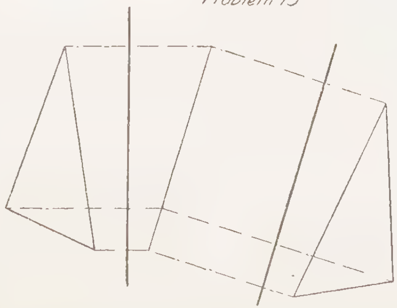
To draw the full view, the plane of the given surface, or any other plane parallel thereto, is turned on one of its traces until it coincides with, or is parallel to, the principal plane containing the trace around which the auxiliary plane was



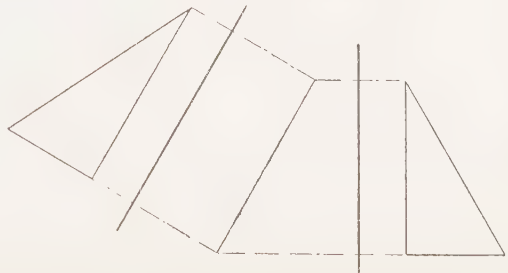
Problem 13



Problem 14



Problem 15



Problem 16

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turned. The outline of the surface is then projected on the auxiliary plane point by point from its given projections on two principal planes.

7. PROBLEM 13. Sheet I.—The horizontal and front projections of a triangular plane surface are shown full size in Fig. 15. Draw a full view of the surface.

SOLUTION.—Transfer the two projections of the triangle to the paper on which the problem is being drawn, locating the left projection line $\frac{1}{4}$ inch from the left border line and the horizontal axis $2\frac{1}{8}$ inches from the upper border line. To determine whether or not the triangular surface is in a plane inclined to two principal planes and perpendicular to the third, construct a side view, alongside of either the horizontal plane or the side plane. In the solution shown on the reduced copy of Sheet I, the side view is drawn at the right of the horizontal plane; it is suggested that the side

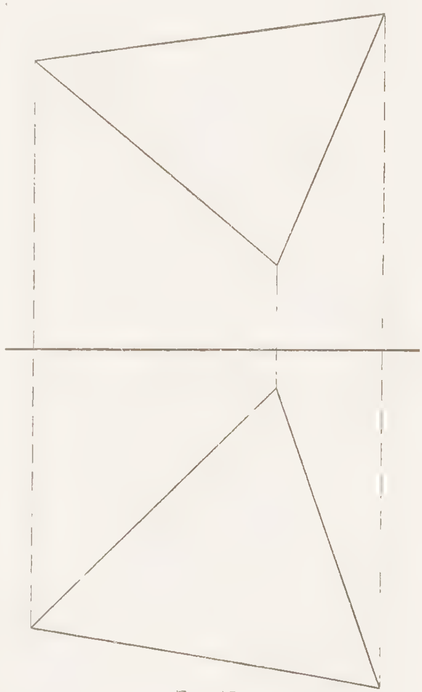


FIG. 15

axis be located about $2\frac{3}{8}$ inches from the left border line. If the work is carefully done, the side view will be a straight line, thus proving that the plane of the given oblique surface is perpendicular to one principal plane—the side plane in this instance. Consequently, the side trace of any auxiliary plane parallel to the given surface is parallel to the side view. For convenience, the auxiliary plane may be taken in such a

manner that it passes through the horizontal axis, in which case its horizontal trace coincides with the horizontal axis and the side trace intersects the intersection of the horizontal and side axes. The side trace having been drawn, draw projection lines from the points *a*, *b*, and *c* of the side view into the auxiliary plane. On these projection lines lay off from the side trace the distances the corners of the triangle are from the side plane, either by transferring the distances with dividers or by using the graphical method indicated on the reduced copy of Sheet I, Exercise II. In the latter case, it will be necessary to draw the revolved horizontal trace, as shown. Join the projections of the corners on the auxiliary plane by straight lines; the resulting triangle is the required full view, in which each line shows in its true length and each angle in its true size.

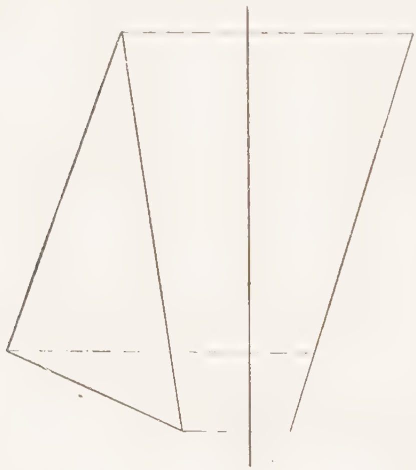


Fig. 16

Problem 14.—Draw a full view of the triangle whose projections are shown in Fig. 15, taking the auxiliary plane so that it passes through the horizontal axes and turning the auxiliary plane on its horizontal trace into the front plane.

Locate the horizontal axis $2\frac{1}{8}$ inches from the upper border line and the side axis $2\frac{13}{16}$ inches from the right border line.

Observe that this is a second solution of Problem 13, differing in that the auxiliary plane is turned on a different trace in this case.

Problem 15.—From the front and side projections of the figure shown in Fig. 16 draw a full view, turning the auxiliary plane on its side trace. The side plane is at the right of the front plane.

Locate the vertical axis $1\frac{7}{8}$ inches from the left border line and the side trace about $1\frac{1}{4}$ inches from the side projection.

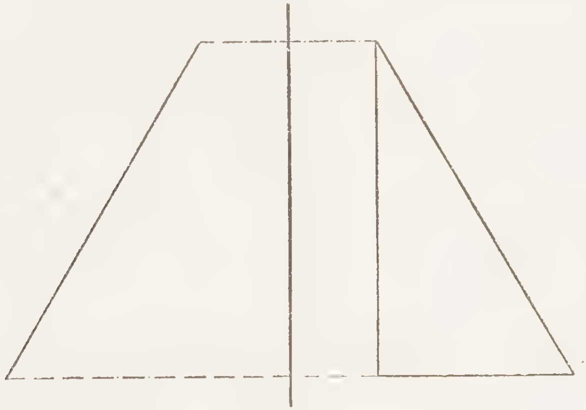


FIG. 17

PROBLEM 16.—From the front and side projections of the figure shown in Fig. 17, the side plane being at the right of the front plane, draw a full view, turning the auxiliary plane on its front trace.

The vertical axis may be located about $2\frac{1}{16}$ inches from the right border line and the front trace about 1 inch from the front projection.

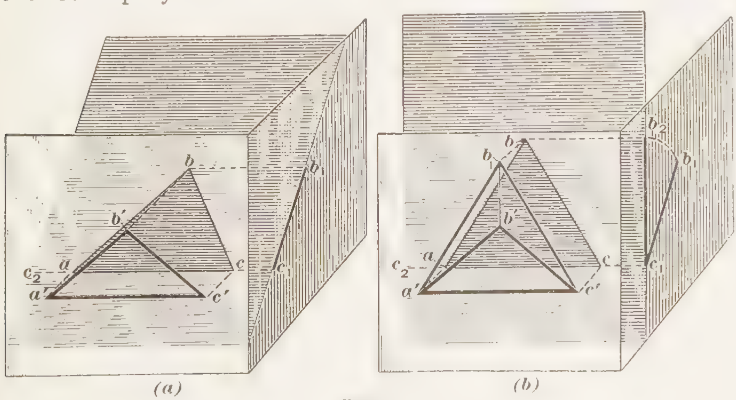


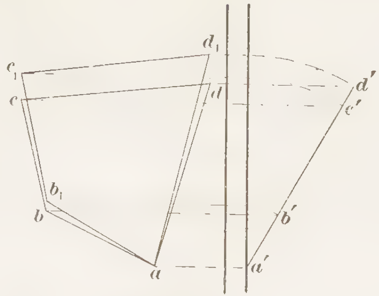
FIG. 18

8. In many cases a full view of a plane surface inclined to two of the principal planes is most conveniently obtained

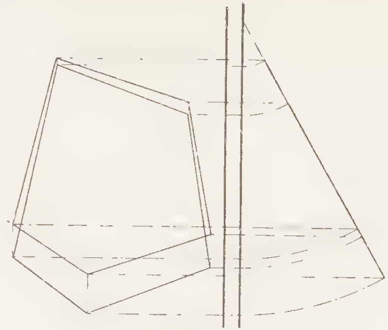
by the second method mentioned in Art. **5**, that is, by turning the plane of the surface until it is parallel to one of the principal planes, turning it on some line within it parallel to that principal plane. Thus, in Fig. 18 (*a*), the figure $a\,b\,c$, as indicated by its front projection $a'\,b'\,c'$ and side projection b_1, c_1, is in a plane oblique to the front plane and perpendicular to the side plane. If the plane containing the figure is now turned on some line within it and parallel to the front plane, as the line $c_1\,c_2$ for instance, until this plane is parallel to the front plane, as shown in Fig. 18 (*b*), the full view can be readily projected on the front plane. Referring to Fig. 18 (*b*), it will be noted that, in turning the plane containing the figure, the side projection $b_1\,c_1$ is turned around c_1 as a center until it is parallel to the vertical axis. Furthermore, in turning the plane of the figure, owing to the fact that the axis of rotation $c_1\,c_2$ is perpendicular to the side plane, the points a, b, and c of the figure remain the same distance from the side plane. As the axis of rotation was chosen so as to pass through the points a and c, the front projections a' and c' remain stationary and the projection b' moves vertically upwards; its distance from the horizontal plane is given by the new side projection $c_1\,b_2$.

Particular attention is called to the fact that the line on which the plane of the surface is turned to bring that surface parallel to a principal plane must be at right angles to that principal plane on which a projection of the surface shows as a straight line. Although in Fig. 18 the line, or axis of rotation $c_1\,c_2$, coincides with the edge $a\,c$ of the surface, this is by no means necessary; neither is the axis of rotation necessarily parallel to an edge of the given surface. Furthermore, the axis of rotation may lie entirely outside of the given surface; in fact, it may be located where it is most convenient to do so. Generally speaking, it is desirable, however, to have the axis of rotation lie in the plane containing the given surface, as the line $c_1\,c_2$ in Fig. 18.

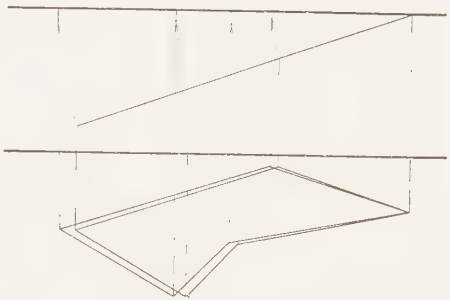
An objection urged against the method of obtaining a full view that has just been explained is that the full view and one of the projections will often overlap on the drawing; the



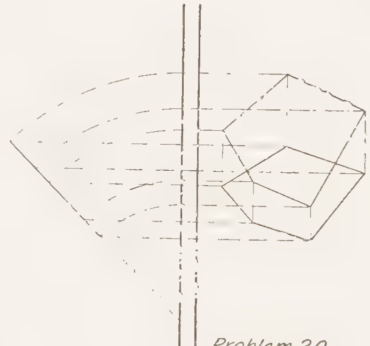
Problem 17



Problem 18



Problem 19



Problem 20

Date

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question of whether this objection is valid in any given case must be decided by the exercise of judgment.

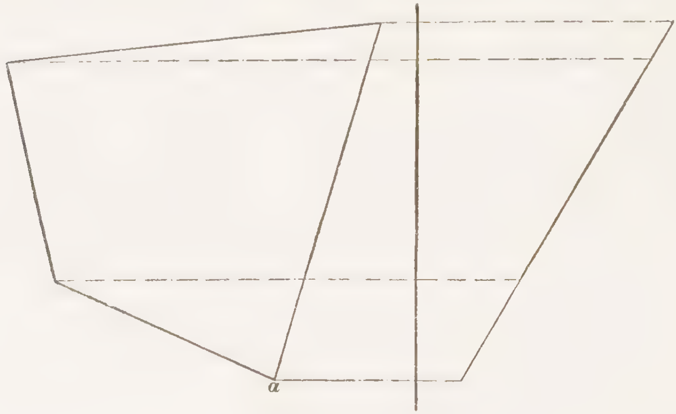


FIG. 19

9. PROBLEM 17. Sheet II.—Draw a full view of the surface whose projections are shown in Fig. 19, turning the plane of the surface on an axis passing through the corner *a* and parallel to the horizontal and front planes.

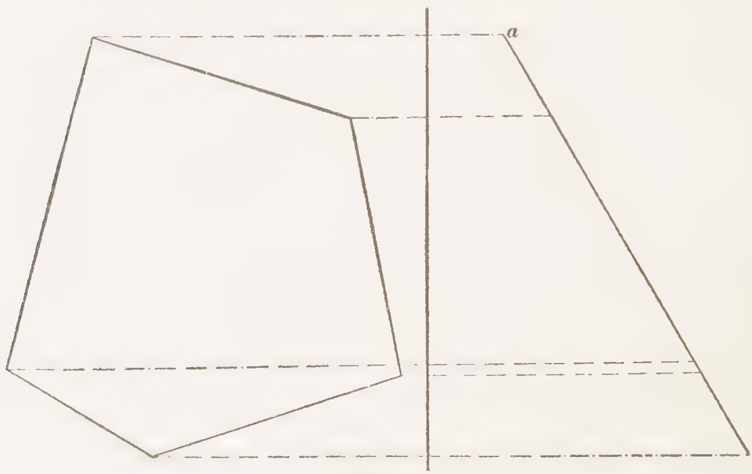


FIG. 20

SOLUTION.—Referring to the reduced copy of Sheet II, Exercise II, draw the vertical axis about $3\frac{1}{4}$ inches from the

left border line. Transfer the projections shown in Fig. 19 by means of dividers, locating the corner *a* about 3¼ inches from the upper border line. Through the side projection *a′* draw a line parallel to the vertical axis, which line represents the side trace of the plane of the surface after it has been turned parallel to the front plane. With *a′* as a center and *a′ b′*, *a′ c′*, and *a′ d′* as radii, describe arcs intersecting the side trace. From the points of intersection draw projection lines into the front plane to intersect projection lines

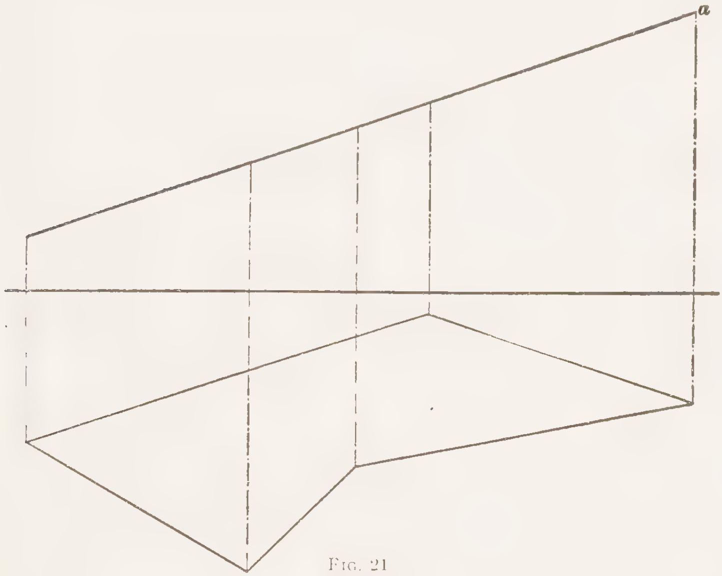


FIG. 21

drawn from the corners *b*, *c*, and *d* and parallel to the vertical axis. The points of intersection are marked b_1, c_1, and d_1, respectively. Join *a* and b_1, b_1 and c_1, c_1 and d_1, d_1 and *a*, by straight lines; the figure $a\, b_1\, c_1\, d_1$ is the required full view.

PROBLEM 18.—Draw a full view of the surface whose projections are shown in Fig. 20, turning the plane of the surface parallel to the front plane on an axis located ½ inch upwards from the corner *a* and in the plane containing the surface.

Locate the vertical axis about 2⅝ inches from the right border line and the point *a* about ¾ inch from the upper border line.

PROBLEM 19.—Draw a full view of the surface whose horizontal and front projections are shown in Fig. 21, turning the

FIG. 22

plane of the surface parallel to the front plane on an axis passing through a.

Locate the horizontal axis 2 inches from the lower border line and the point a $4\frac{9}{16}$ inches from the left border line.

PROBLEM 20.—Draw a full view of the surface whose side and front projections are shown in Fig. 22, turning the plane

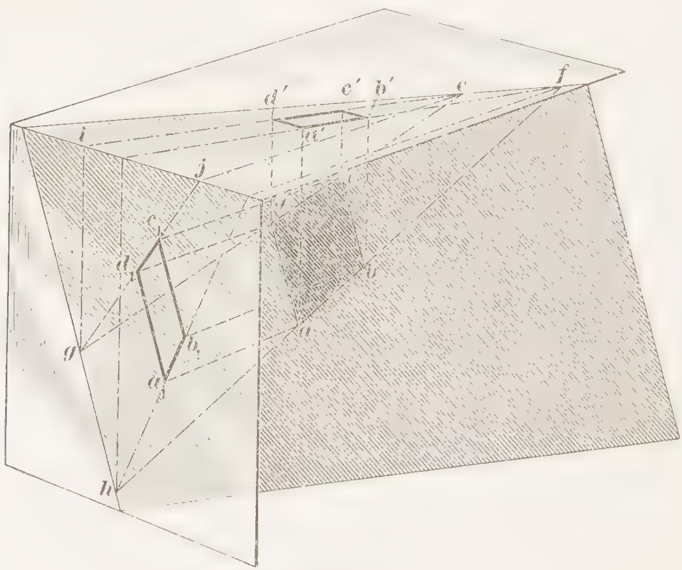


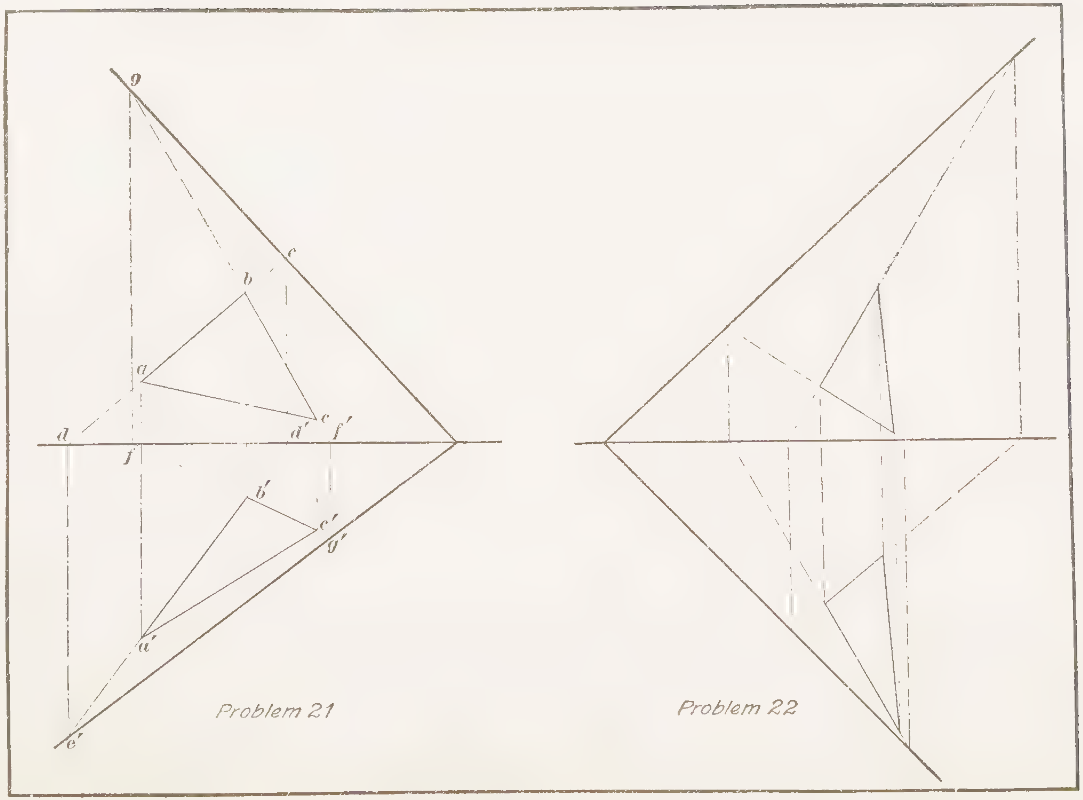
FIG. 23

of the surface on an axis situated in this surface and $1\frac{3}{16}$ inches below the point a.

Locate the vertical axis $2\frac{5}{8}$ inches from the right border line and the point a $1\frac{5}{16}$ inches from the lower border line.

10. When the plane of a given surface is inclined to the three principal planes and it is required to show the full view either on the plane containing the surface or on an auxiliary plane parallel to the plane of the surface, it becomes necessary to find the traces of the plane containing the surface from the projections of that surface. The principle involved in finding the traces from the projections is illustrated in Fig. 23, where $a\,b\,c\,d$ is a surface inclined to the three principal planes, $a'\,b'\,c'\,d'$ the horizontal projection, and $a_1\,b_1\,c_1\,d_1$ the front projection. If, now, two straight lines of the surface $a\,b\,c\,d$, as the lines $a\,b$ and $c\,d$ for instance, are produced until they pierce the horizontal plane at e and f and the front plane at g and h, it will be evident that the points e and f are two points in the horizontal trace, and that g and h are two points in the front trace of the plane containing the surface, since the lines $e\,g$ and $f\,h$ lie in that plane. Consequently, if the points e and f and g and h are determined from the projections $a'\,b'\,c'\,d'$ and $a_1\,b_1\,c_1\,d_1$, the exact location of the horizontal and front traces is obtained by drawing a straight line through e and f and through g and h, respectively; these lines intersect in the horizontal axis.

Since the line $d'\,c'$ is the horizontal projection of the line $d\,c$, it follows that by producing the line $d'\,c'$, as indicated by the line $i\,d'\,c'\,e$, a horizontal projection of the line $e\,g$ is obtained. Likewise, by producing the front projection $d_1\,c_1$ a front projection of $e\,g$ is given. Now consider the triangle $i\,e\,g$ as an auxiliary plane; this plane, since it contains the projectors $d\,d'$ and $c\,c'$, is perpendicular to the horizontal plane, and consequently its front trace $i\,g$ is perpendicular to the horizontal axis. Likewise, considering the triangle $e\,j\,g$ as an auxiliary plane, its horizontal trace $j\,e$ is perpendicular to the horizontal axis. Then, if the front and horizontal projections of the line $d\,c$ are produced until they intersect the horizontal axis at i and j, respectively, and if perpendiculars are erected at i and j, the intersection of these perpendiculars


g
b
c
a
c
d
d′
f′
f
b′
c′
g′
a′
e′
Problem 21
Problem 22

with the projections $d' c'$ and $d_1 c_1$ produced gives the points e and g where the line $d c$ produced in both directions pierces the horizontal and front planes. In the same manner are found the points f and h where the line $a b$ produced in both directions pierces the horizontal and front planes.

11. PROBLEM 21. Sheet III.—Find the horizontal and front traces of the plane containing the surface whose horizontal and front projections are shown in Fig. 24.

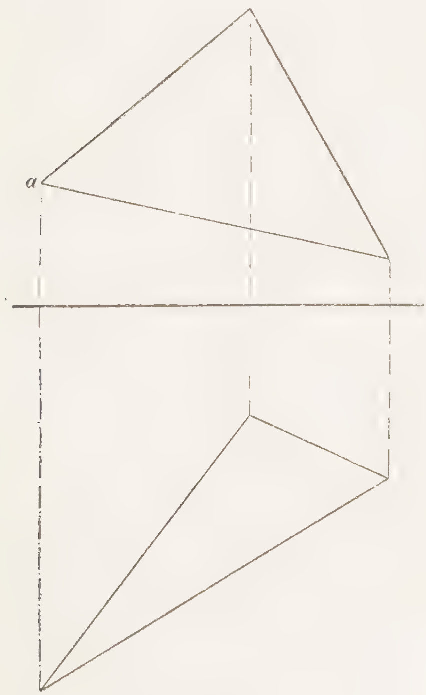
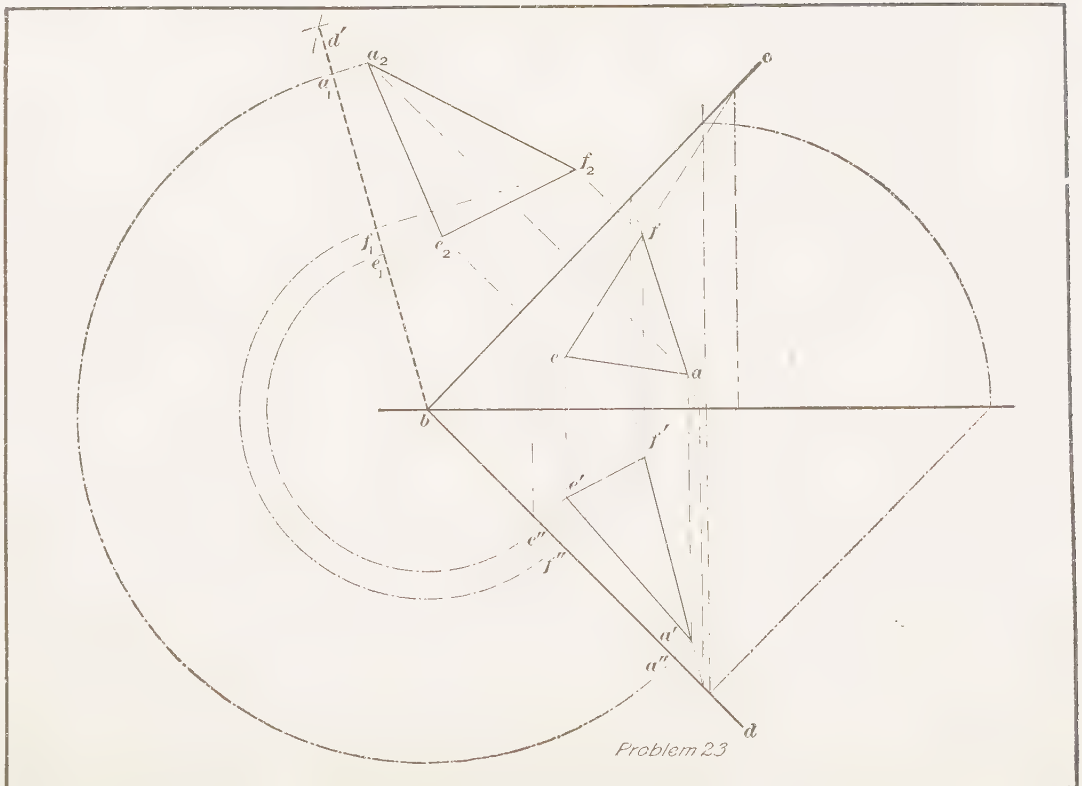


FIG. 24

FIG. 25

SOLUTION.—Referring to the reduced copy of Sheet III, Exercise II, draw the horizontal axis about $3\frac{9}{16}$ inches from the lower border line and draw the two given projections


d'
a_2
a_1
e
f_2
f
f_1
e_1
e_2
e
a
b
f'
e'
e''
f''
a'
a''
d
Problem 23

locating the corner *a*, Fig. 24, $1\frac{3}{8}$ inches from the left border line. Produce the projection *a b* until it intersects the horizontal axis at *d* and produce the front projection $a'\,b'$ until it intersects the same axis at d'. Also produce both *a b* and $a'\,b'$ in a direction away from the axis. At *d* and d' erect perpendiculars; their intersections *e* and e' with *a b* and $a'\,b'$ produced are points in the horizontal and front traces. Produce *b c* and $b'\,c'$, and erect perpendiculars at the intersections *f* and f' to intersect *b c* and $b'\,c'$ produced in *g* and g'. Through the points *g* and *e* draw the horizontal trace; through g' and e' draw the front trace.

If the work has been accurately done, the two traces intersect on the horizontal axis.

Problem 22.—Find the horizontal and front traces of the plane containing the surface whose horizontal and front projections are shown in Fig. 25.

Locate the horizontal axis about $3\frac{9}{16}$ inches from the lower border line and the corner *a* $1\frac{13}{16}$ inches from the right border line.

12. Problem 23. Sheet IV.—Show a full view of the surface whose horizontal and front projections are given in Fig. 26 (*a*), drawing this view on the plane containing the surface and turning the plane on its horizontal trace into the horizontal plane, as indicated in Fig. 26 (*b*).

Solution.—Referring to the reduced copy of Sheet IV, Exercise II, draw the horizontal axis $3\frac{7}{8}$ inches from the lower border line and draw the two projections given in Fig. 26 (*a*), locating the corner *a* $3\frac{15}{16}$ inches from the right border line. Next, find the horizontal trace *b c* and the front trace *b d* of the plane containing the surface, and find the revolved front trace $b\,d'$. From the corners *a*, *e*, and *f* draw projection lines across the horizontal trace into the plane of the surface (turned into the horizontal plane). From the corners a', e', and f' draw projection lines to the front trace, intersecting this at a'', e'', and f''. Transfer the distances $b\,e''$, $b\,f''$, and $b\,a''$ to the revolved front trace $b\,d'$.

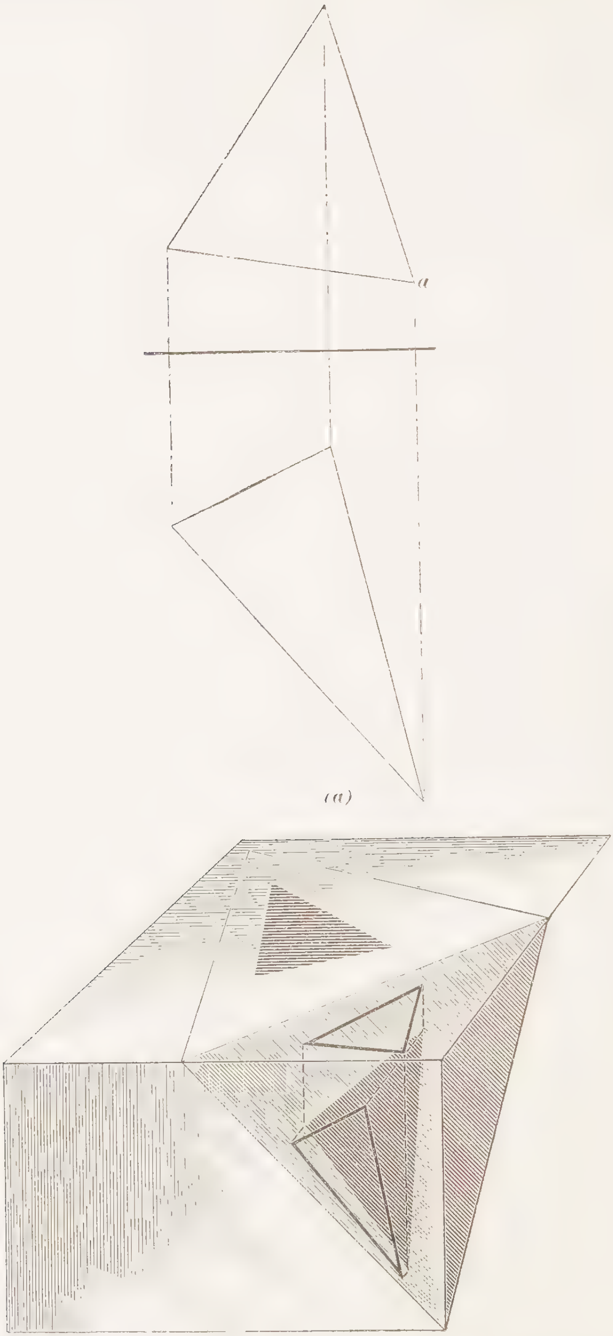
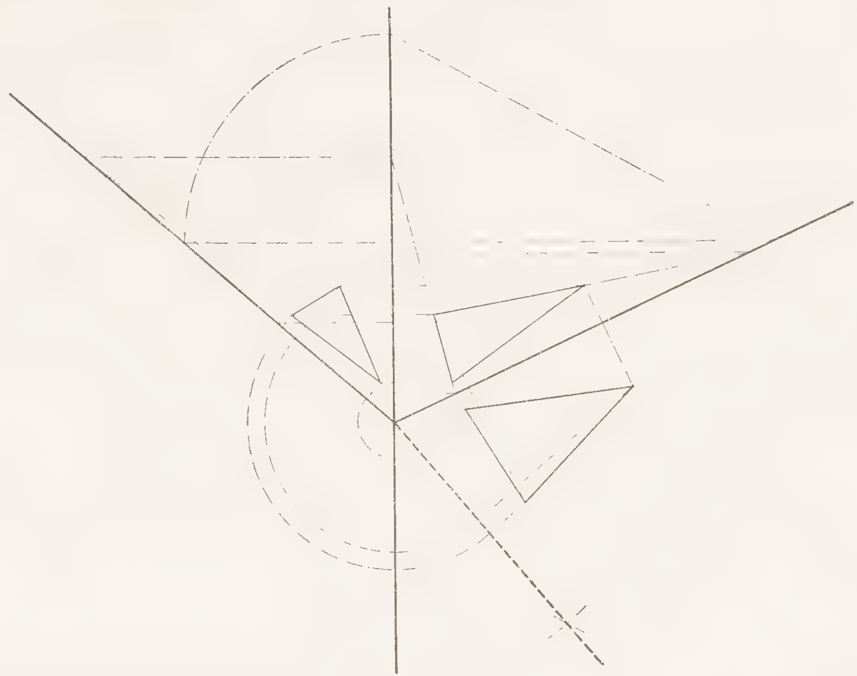


Fig. 26



Problem 24

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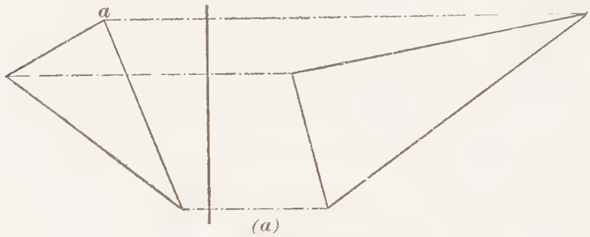
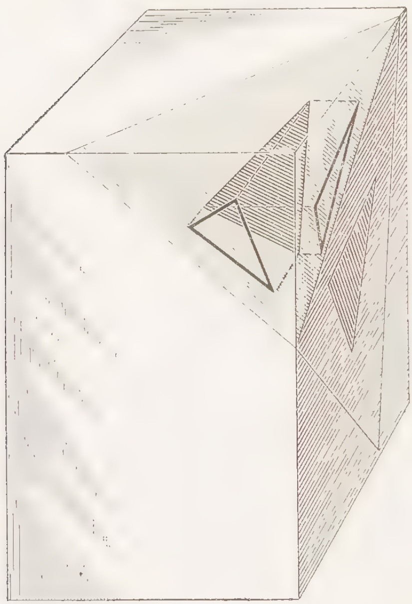
At the points a_1, f_1, and e_1, erect perpendiculars intersecting the projection lines drawn from a, e, and f at a_2, e_2, and f_2. Join a_2, e_2, and f_2 by straight lines to obtain the required full view.



(a)



(b)

FIG. 27

It will be obvious that finding the required full view resolves itself into finding the projection of three points on a plane oblique to the three principal planes, this oblique plane having been turned on one of its traces into the plane of the drawing.

13. PROBLEM 24. Sheet V.—Show a full view of the surface whose front and right side projections are given in Fig. 27 (*a*), turning the plane containing the surface on its side trace into the side plane, as indicated in Fig. 27 (*b*).

Locate the vertical axis $5\frac{11}{16}$ inches from the right border line and the corner *a*, Fig. 27 (*a*), $3\frac{7}{16}$ inches from the upper border line.

EXERCISE III

14. An objection raised against the method given in Arts. **10** to **12** for obtaining a full view of a surface, is that in practice the construction lines will often extend far beyond the drawing board, which renders difficult the application of this method in such cases. For this reason it is well for the student to be familiar with another method of obtaining full views, which is an extension, or modification, of the method explained in Art. **8.**

When a full view of a surface oblique to the three principal planes is to be drawn, there are two cases that arise in practice. In the one case, no line of the surface is shown in its true length; in the second case, one line is shown in its true length in one of its projections. It may be repeated here that the true length of a line is given if one of its three projections is parallel to one of the axes, or, in other words, if it lies in a plane parallel to one of the principal planes.

When the plane of a surface is oblique to all three principal planes, the first step in the method now under discussion, assuming that no line shows in its true length on any projection, is to turn the plane of the surface in such a manner that some line will show in its true length in one of the projections, which occurs when it lies in a plane parallel to one of the principal planes.

In Fig. 28 (*a*), let $a\ b\ c$ be the given surface represented by its horizontal projection $a'\ b'\ c'$ and front projection $a_1\ b_1\ c_1$. None of the lines in either projection are parallel to an axis, and consequently none shows in its true length. Let it be decided to turn the plane of the surface so that one of the projections of the line $a\ b$ will show in its true length, say the

front projection. Turn the plane of the surface $a\,b\,c$ on any axis perpendicular to the horizontal plane, say on the projector $b\,b'$, in such a manner that the points a and c remain the same distance from the horizontal plane and until the horizontal projection $a'\,b'$ is parallel to the front axis. This

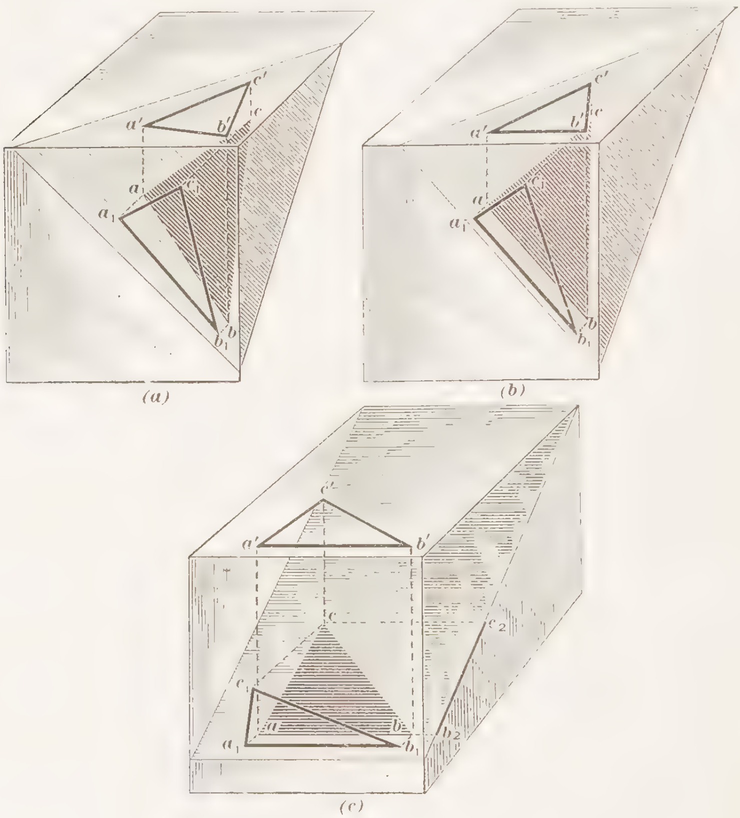


FIG. 28

turning of the plane of the surface does not change the outline $a'\,b'\,c'$ of the horizontal projection; it merely shifts the position of the corners a' and c' on the horizontal plane. In other words, turning the plane of the surface about $b\,b'$ as an axis results in rotating the projection $a'\,b'\,c'$ about b' as a center into the position shown in Fig. 28 (b). The front

projection $a_1 b_1 c_1$ in Fig. 28 (b) will be different than in Fig. 28 (a); it is found on a drawing by projecting the corners a' and c' downwards on lines drawn parallel to the horizontal axis and through the original positions of the corners a_1 and c_1. The distance $a_1 b_1$, Fig. 28 (b), is the true length of the line $a b$, since the line $a b$ is now parallel to the front plane.

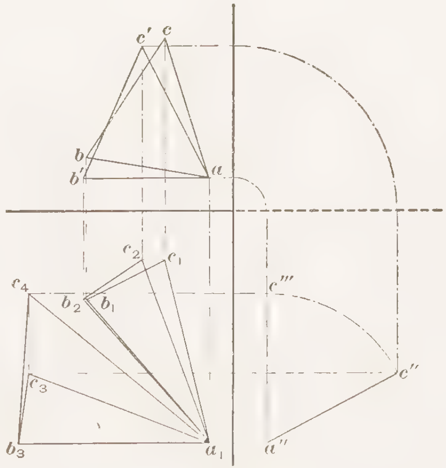
The next step is to turn the plane of the surface so that the line shown in its true length will be parallel to an axis. Thus, turn the plane of the surface around the projector $b_1 b$ as an axis in such a manner that the horizontal projections of the corners a', b', and c' remain at the same distance from the front plane and until the line $a b$, and hence its front projection $a_1 b_1$ is parallel to the horizontal axis, as shown in Fig. 28 (c). This turning of the plane of the surface does not change the outline $a_1 b_1 c_1$ of the front projection; it merely turns this projection around the corner b_1 as a center. The horizontal projection $a' b' c'$ will be different, however, from what it was in Fig. 28 (b); on a drawing it is found by projecting the new position of the corners a_1 and c_1 into the horizontal plane to meet lines parallel to the horizontal axis and drawn through the second position of the corners a' and c', or that shown in Fig. 28 (b). The plane of the surface is now oblique to the horizontal and front planes and perpendicular to the side plane, the side trace being given by the side projection $b_2 c_2$.

The last step in the operation is to turn the plane of the surface on some line within it and parallel to the front plane until the plane of the surface is parallel to the front plane, which is done in the manner already described in Art. **8.**

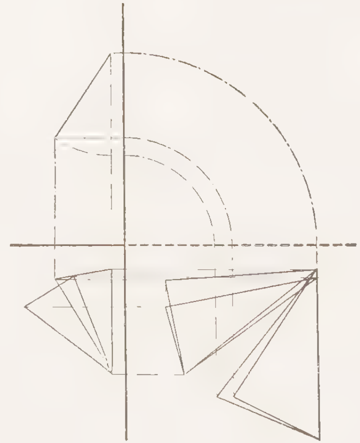
When one of the lines of the given surface shows in its true length in one of the projections, the first operation described is obviously omitted.

15. PROBLEM 25. Sheet I.—From the two projections that are given in Fig. 26 (a), determine the full view by the method explained in Art. **14.**

SOLUTION.—Referring to the reduced copy of Sheet I, Exercise III, draw the two projections, locating the horizon-



Problem 25



Problem 26

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tal axis $3\frac{5}{8}$ inches from the upper border line and the corner a $3\frac{1}{4}$ inches from the left border line. Since no line is parallel to an axis, the first step is to turn the plane of the surface so that some line, say the line $a\,b$, will show in its true length. Draw $a\,b'$ parallel to the horizontal axis, making it equal to $a\,b$. On $a\,b'$ erect the triangle $a\,b'\,c' = a\,b\,c$, this triangle being the new horizontal projection. Draw the new front projection $a_1\,b_2\,c_2$, determining the corners b_2 and c_2 by drawing projection lines from b' and c' to intersect lines parallel to the horizontal axis drawn through b_1 and c_1. The line $a_1\,b_2$ is the true length of the line whose projections are the lines $a\,b$ and $a_1\,b_1$. Draw $a_1\,b_3$ parallel to the horizontal axis, making it equal to $a_1\,b_2$, and construct the new front projection $a_1\,b_3\,c_3$. There is no need to construct the new horizontal projection corresponding to $a_1\,b_3\,c_3$, since the plane of the surface was turned in such a manner that all corners remained the same distance from the front plane, which distances can consequently be ascertained from the horizontal projection $a\,b'\,c'$. Next, construct the side view $a''\,c''$, drawing the vertical and side axis at any convenient distance, say $\frac{1}{4}$ inch, from the corner a. Now turn the plane of the surface about an axis perpendicular to the side plane and passing through a'' until it is parallel to the front plane, which brings the point c'' to c'''. Project c''' into the front plane until the projection line intersects at c_4 a line perpendicular to the horizontal axis and drawn through c_3. Join a_1 and b_3 with c_4 by straight lines; the triangle $a_1\,b_3\,c_4$ is the required full view.

The full view obviously must be equal to that found in solving Problem 23, as the same projections were used.

Problem 26.—From the two projections that are given in Fig. 27 (a), determine the full view by the method explained in Art. **14.**

Locate the vertical axis $3\frac{1}{4}$ inches from the right border line and the corner a $4\frac{3}{8}$ inches from the upper border line.

16. As was mentioned in Art. **5,** a full view of a surface whose plane is oblique to the principal planes can be obtained by dividing the projections of the surface into triangles,

finding the true length of each line of each triangle, and constructing the full view from these true lengths.

In Fig. 29 is shown a quadrilateral surface $a\,b\,c\,d$ whose plane is inclined to the three principal planes, and three projections are given, distinguished by prime marks and subscripts annexed to corresponding letters. Divide the surface by a straight line $a\,c$ into the triangles $a\,b\,c$ and $a\,d\,c$. Joining the projections a' and c', a_1 and c_1, and a_2 and c_2, of the points a and c by straight lines $a'\,c'$, $a_1\,c_1$, and $a_2\,c_2$, gives the three projections of the line $a\,c$. Now, if the true length of the sides $a\,c$, $a\,d$, and $d\,c$ of the triangle $a\,d\,c$, and of the sides $a\,c$, $a\,b$, and $b\,c$ of the triangle $a\,b\,c$ is determined from either two of the three projections, it will be evident that the quadrilateral $a\,b\,c\,d$ can be drawn by first constructing one of the triangles, as $a\,b\,c$ for instance, and then on the side $a\,c$ the triangle $a\,c\,d$.

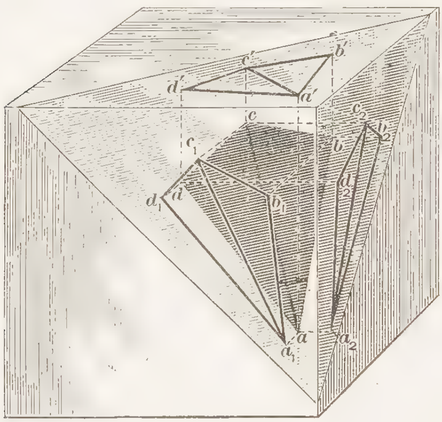
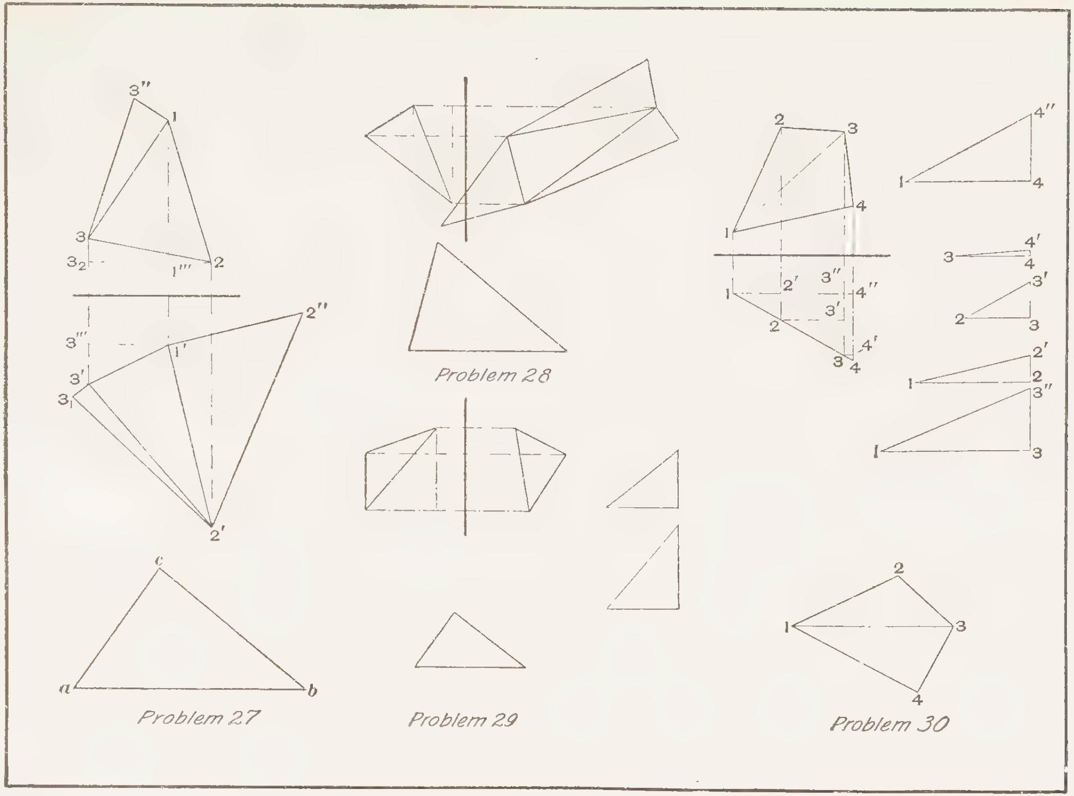


Fig. 29

For the sake of clearness of illustration, a very simple outline was chosen; the principle involved is the same, however, with the most complex outline.

17. Problem 27. Sheet II.—From the two projections given in Fig. 26 (a), determine the full view by the method explained in Art. **16.**

Solution.—Referring to the reduced copy of Sheet II, Exercise III, draw the projections given in Fig. 26 (a), locating the corner marked a in that figure $2\frac{5}{8}$ inches from the upper border line and $2\frac{1}{8}$ inches from the left border line. To find the true length of the line whose one projection is *1–3*, construct a right-angled triangle having *1–3* for one of the



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adjacent sides and $1\text{–}3'' = 3'\text{–}3'''$ for the other. The hypotenuse $3\text{–}3''$ is the true length of the line whose horizontal projection is $1\text{–}3$.

It must be clearly understood that the true length of a line can be found by erecting a right-angled triangle on either one of the given projections, or the right-angled triangle may be constructed entirely separate from the given projections of the surface, just as may be most convenient.

To find the length of the line whose front projection is $1'\text{–}2'$, construct the right-angled triangle $1'\text{–}2'\text{–}2''$, in which the side $1'\text{–}2'' = 1'\text{–}1'''$. Likewise, to find the true length of the line whose front projection is $2'\text{–}3'$, construct the right-angled triangle $2'\text{–}3'\text{–}3_1$, in which the side $3'\text{–}3_1 = 3\text{–}3_2$.

With the hypotenuses $3\text{–}3''$, $2'\text{–}3_1$, and $2'\text{–}2''$ construct the triangle $a\,b\,c$, which will be the required full view.

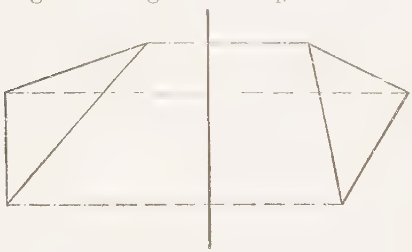


Fig. 30

Problem 28.—Show a full view of the triangle whose front and right side projections are given in Fig. 27 (a), using the method described in Art. **16** and drawing the triangles on the side projection.

Locate the vertical axis $4\frac{3}{4}$ inches from the left border line and the corner a, Fig. 27 (a), 1 inch from the upper border line.

Problem 29.—Draw a full view of the triangular surface whose front and right side projections are shown in Fig. 30, using the method explained in Art. **16.** Observe that the front projection of one line is parallel to the vertical axis.

Locate the vertical axis $4\frac{3}{4}$ inches from the left border line and the lower corner of the projections $2\frac{7}{8}$ inches from the bottom border line.

Draw the triangles by which the true length of the lines is determined to the right of the projections, and the full view below the projections, as indicated on the reduced copy of Sheet II, Exercise III.

PROBLEM 30.—Draw a full view of the quadrilateral plane surface whose horizontal and front projections are shown in Fig. 31, using the triangulation method explained in Art. **16.**

SOLUTION.—Referring to the reduced copy of Sheet II, Exercise III, draw the two projections, locating the horizontal axis $2\frac{1}{2}$ inches from the upper border line and the extreme left of the projections $3\frac{7}{16}$ inches from the right border line.

Divide the horizontal projection *1–2–3–4* into two triangles by drawing a straight line through two opposite corners, as *1* and *3* for instance. The front projection of the line *1–3* in the horizontal view is given by the straight line *1–3* in the front view. If the plane of the given quadrilateral surface had been inclined to the three principal planes, the front projection of the line *1–3* in the horizontal view would obviously not coincide with the straight line representing the front view in this particular case, in which the plane of the surface is perpendicular to the front plane and inclined to the horizontal and side planes.

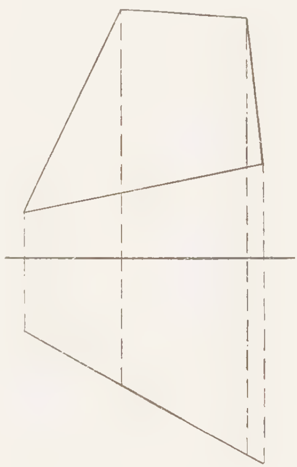
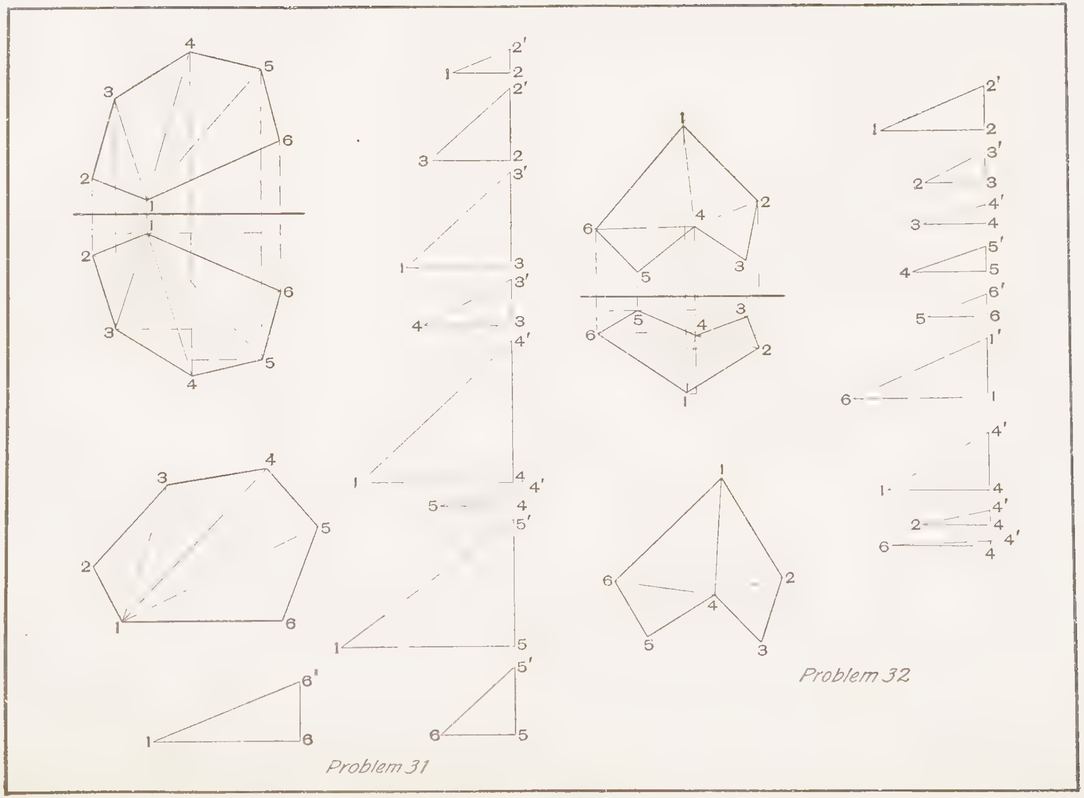


FIG. 31

To find the true length of the projection *1–4*, draw the right-angled triangle *1–4–4″*, in which the side *1–4* equals the horizontal projection *1–4*, and the side *4–4″* equals the distance *4–4″* of the front view. In a similar manner, find the true lengths of the horizontal projections *4–3*, *3–2*, *2–1*, and *1–3*.

To draw the full view, draw the triangle *1–2–3*, making the side *1–2* = *1–2′*, *2–3* = *2–3′*, and *1–3* = *1–3″*. On the side *1–3* erect the triangle *1–3–4*, in which the side *1–4* = *1–4″*, and *3–4* = *3–4′*.

18. PROBLEM 31. Sheet III.—From the two projections given in Fig. 32, draw the full view by the method given in Art. **16.**



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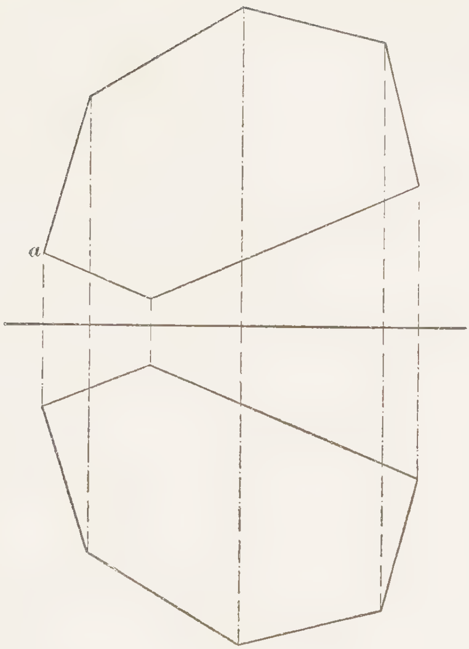


Fig. 32

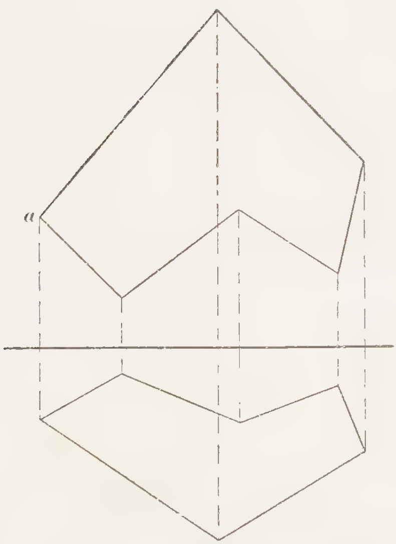


Fig. 33

Locate the corner *a*, Fig. 32, $\frac{7}{8}$ inch from the left border line and the horizontal axis $2\frac{1}{8}$ inches from the upper border line.

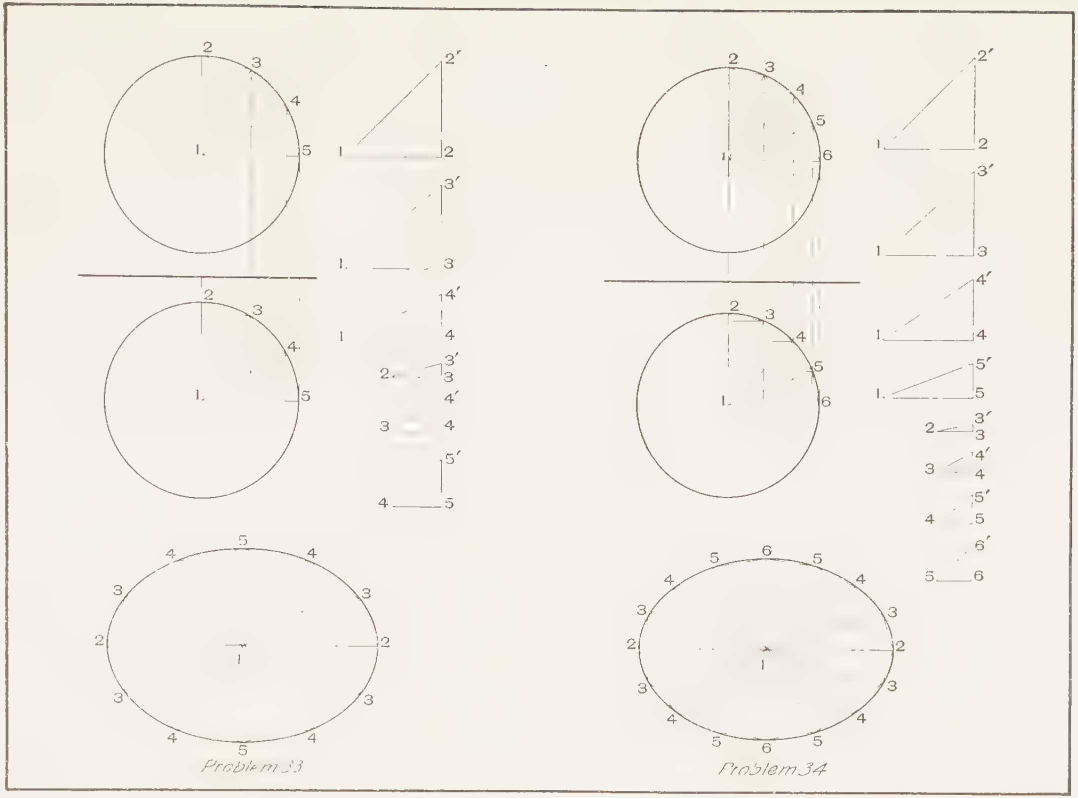
PROBLEM 32.—From the two projections given in Fig. 33, construct the full view by the method given in Art. **16.**

Locate the corner *a* $4\frac{7}{8}$ inches from the right border line and the horizontal axis 3 inches from the upper border line.

19. PROBLEM 33. Sheet IV.—The horizontal and front projections of a plane surface are circles having a diameter of 2 inches; the center of each projection is $1\frac{1}{4}$ inches from the horizontal axis. Draw the full view by the method given in Art. **16.**

SOLUTION.—Draw the two projections in any convenient location, say with their centers 2 inches from the left border line and the horizontal axis $2\frac{3}{4}$ inches from the upper border line. Since the two projections are symmetrical, the surface represented by them will also be symmetrical; consequently, if the true lengths of lines of triangles constructed in one quarter of each projection is determined, the true lengths of the lines of similar triangles in the remaining three quarters is also known.

Referring to the reduced copy of Sheet IV, Exercise III, draw straight lines *1–2* and *1–5* from the center of each projection, the lines *1–2* being perpendicular to the horizontal axis and the lines *1–5* parallel to that axis. The sectors *1–2–5* are each a quarter of each projection. Establish a number of points on one of the arcs *2–5* and project these points to the other arc; the number of points chosen is entirely a matter of judgment, and they may or may not be spaced equal distances apart on the arcs, just as preferred. In the solution presented, the arcs *2–5* have been divided into three equal parts, thus establishing the points *3* and *4*. Now draw the triangles *1–2–3*, *1–3–4*, *1–4–5* in both projections. Determine the true lengths of the lines *1–2*, *1–3*, *1–4*, *2–3*, *3–4*, and *4–5* of one of the projections, say the horizontal projection, by drawing the triangles shown to the right of the projections.



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Since the two lines *1–5* are parallel to the horizontal axis, both show the true length of the corresponding line on the surface whose full view is desired.

To construct the full view, draw the lines *2–2* and *5–5* in any convenient location, say so as to have their intersection *1* $2\frac{7}{16}$ inches from the left border line and $1\frac{1}{2}$ inches from the lower border line. Make the lengths *1–5* equal to *1–5* of the given projections, and $1–2 = 1–2'$. With the true lengths of the lines, construct the triangles *1–2–3*, *1–3–4*, and *1–4–5*; through the corners *2*, *3*, *4*, and *5*, draw the required outline, using an irregular curve.

Problem 34.—The horizontal and front projections of a plane surface are circles having a diameter of $1\frac{7}{8}$ inches; the center of each circle is $1\frac{1}{4}$ inches from the horizontal axis. Draw the full view by the method used in solving Problem 33, locating the center of the full view $1\frac{1}{2}$ inches from the lower border line and $3\frac{1}{8}$ inches from the right border line.

Locate the center of the projections $3\frac{9}{16}$ inches from the right border line, and the horizontal axis $2\frac{3}{4}$ inches from the upper border line.

PRACTICAL PROJECTION
(PART 4)

PROJECTION OF SOLIDS

PROJECTION OF SOLIDS BOUNDED BY PLANE SURFACES

EXERCISE I

1. In the projection of solids, no new principles are encountered, since solids are merely combinations of various surfaces, and these surfaces are projected one by one in the same manner as was shown in preceding problems.

Since surfaces intersect in a line, it is only necessary, in drawing the projections of solids, to find, in any view or views, the projections of those lines that represent the correct intersections of the adjacent surfaces. The projections of the lines of intersection are found by projecting points defining these lines; hence, the projection of solids resolves itself into the projection of points.

2. When the form of a solid is such that, in any view, one surface is hidden by another, the outline of the hidden surface is frequently conventionally defined by dotted lines on the drawing. This applies also to projections in which two or more solids are shown in such positions that some of their surfaces are completely or partly hidden by other surfaces nearer the eye of the observer. Only such surfaces on which the lines of sight fall directly are shown in a view by

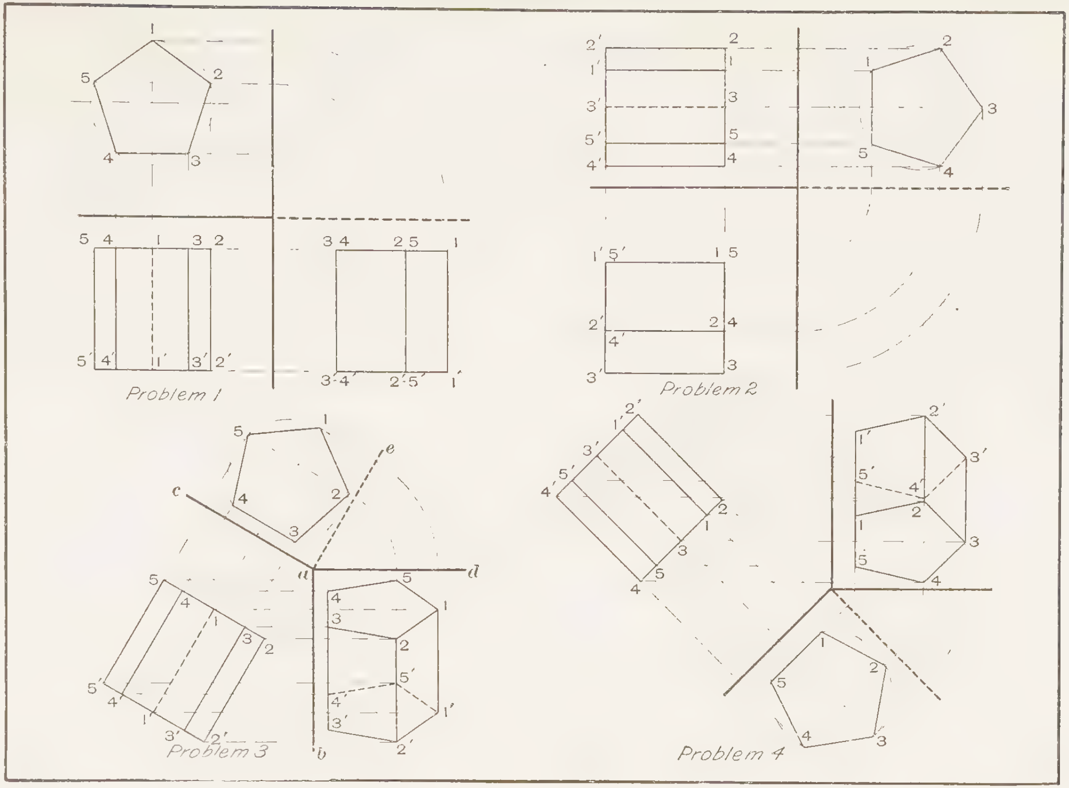
full lines, although, as mentioned above, the outline of such other surfaces as it may be desirable to show in a drawing may be indicated by dotted lines.

The reading of working drawings is a comparatively easy matter, if each portion of the object represented is resolved into its respective surfaces, and the various outlines looked for as they are shown in the different projections. If this is found to be a difficult task, the surfaces may be further resolved into lines and points, whose respective positions may then be located in each view shown. It is not to be expected that the position of every surface in a complicated drawing will be seen by the beginner at a single glance—a man of long experience seldom has such proficiency. The complicated drawings become easily understood by careful study of the various positions of the surfaces composing the solids that are projected in the problems.

3. It has been found convenient, when making projections of objects, to make use of a line that is imagined to pass through the central portion of the solid as it is shown in any plan and elevation. Such a line is called a *center line*, and in many projections it is inked in when the drawing is finished, since it frequently affords a convenient means of indicating certain positions of the figure, besides assisting in the location of the several surfaces of the solid in the different views. This line, however, is central only in its relation to the object of which the drawing is a representation, and not in relation to the planes of projection. This may be better understood by considering the center line as the projection of an imaginary surface (or plane) that passes through the central portion of the figure. It is generally represented in those views only in which that imaginary surface can be shown in one line.

4. In the projection of solids, the first question that presents itself is which of the projections should be drawn first. No definite rule is possible by which to answer this question; the general rule is to draw that projection first which is easiest to draw from the known form and dimensions of the solid. Thus, in the case of a prism or pyramid, with its

Exercise I — Practical Projection, Part 4 — Sheet I



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center line parallel to two of the principal planes, it is easiest to draw the full view of one end or the base; with a cone, with the diameter and height given and its center line perpendicular to one and parallel to two principal planes, either one of the three projections can be drawn first with equal facility. The same statement applies to a cylinder placed in the same manner. When the center line is inclined to two or to all principal planes, the work is started from some full view.

5. Problem 1. Sheet I.—A regular pentagonal prism is shown in perspective in Fig. 1. In this prism the ends are pentagons with equal sides and inscribed in a circle having a diameter of $1\frac{9}{32}$ inches; the five sides are parallelograms $1\frac{1}{4}$ inches high.

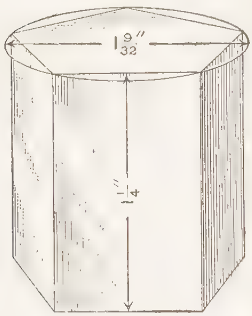


Fig. 1

One side of the prism being parallel to the front plane and the two ends parallel to the horizontal plane, draw a front projection, right side projection, and horizontal projection, placing the right side projection alongside of the front projection.

Solution.—Referring to the reduced copy of Sheet I, Exercise I, in any convenient location, say $2\frac{1}{8}$ inches from the upper border line, draw the horizontal axis; likewise, say $2\frac{3}{4}$ inches from the left border line, draw the vertical and side axes. Since the location of the prism in reference to the principal planes is not given, draw on the horizontal plane, in any convenient location, a circle having a diameter of $1\frac{9}{32}$ inches, and through its center draw a projection line into the front plane. Beginning at the intersection *1* of this projection line, divide the circle into five equal parts, and draw the straight lines *1–2*, *2–3*, etc., thereby completing the required horizontal projection. If the division has been accurately made, the horizontal projection *3–4* is parallel to the horizontal axis, indicating that the side of the prism of which *3–4* is the horizontal projection, is parallel to the front plane.

Since the ends of the prism are parallel to the horizontal plane, in any convenient place on the front plane draw two straight lines $1\frac{1}{4}$ inches apart and parallel to the horizontal axis; on these lines will be the front projection of the top and bottom surfaces. From the horizontal projection project the points *1* to *5* down to the two lines on the front plane. Join the front projections *1* to *5* and *1'* to *5'* by straight lines, making the line *1–1'* dotted to indicate that it represents an edge hidden from view; this completes the front projection.

Owing to the way in which the prism is placed in reference to the front plane, projection lines to the side axis drawn from the points *2* and *5* coincide; this is also true of the projection lines drawn to the same axis from the points *3* and *4*. This indicates that the side projection of the points *2* and *5* will be a single point, which is also true of the points *3* and *4*.

To draw the side view, project the points *1* to *5* in the horizontal projection to the side axis and transfer the intersections of the projection lines with the side axis to the revolved side axis; then draw projection lines into the side plane. Project the points *1* to *5* and *1'* to *5'* from the front projection into the side plane to obtain the side projection of these points; join *1* and *1'* in the side plane, also *2–5* and *2'–5'*, as well as *3–4* and *3'–4'*, by straight lines, which completes the side projection.

The explanation given should make it plain that the projection of solids resolves itself into the projection of points.

Problem 2.—Draw a front projection, horizontal projection, and right side projection of the prism shown in Fig. 1, the side plane being at the right of the horizontal plane. One side of the prism is parallel to the horizontal plane, and the ends are parallel to the side plane.

Locate the horizontal axis $1\frac{13}{16}$ inches from the upper border line and the vertical and side axes $2\frac{3}{4}$ inches from the right border line.

Problem 3.—The prism shown in Fig. 1 is inclined toward the side plane in such a manner that its center line makes an

angle of 30° with that plane, in the direction shown in Fig. 2. The center line is parallel to the front plane. Draw a full view of the top end and a front and side projection, the side plane being at the right of the front plane and one side of the prism being parallel to the front plane.

Solution.—Referring to the reduced copy of Sheet I, Exercise I, draw the vertical axis about $3\frac{3}{16}$ inches from the left border line. Since the center line is parallel to the front plane, its front projection makes an angle of 30° with the vertical axis, and since the ends of the prism are at right angles to the center line, they are in planes making an angle of $90+30=120°$ with the side plane and perpendicular to the front plane. Consequently, the plane on which a full end view is drawn makes an angle of 120° with the side plane, and since it is perpendicular to the front plane, its front trace makes an angle of 120° with the vertical axis. Therefore, at any convenient point on the vertical axis $a\,b$, say $2\frac{3}{16}$ inches from the lower border line, draw the front trace $a\,c$ at an inclination of 120° to $a\,b$, and draw the side trace $a\,d$ at right angles to $a\,b$. Draw the revolved side trace $a\,e$ at right angles to $a\,c$. The side trace and revolved side trace are drawn at right angles to the front trace and vertical axis because the auxiliary plane is perpendicular to the front plane. In any convenient location on the auxiliary plane, construct the full view of the ends of the prism, taking care to have one side parallel to the front trace. From this full view project the front view, remembering that the height of the prism is $1\frac{1}{4}$ inches, and finally from the full view and front view project the side view, point by point.

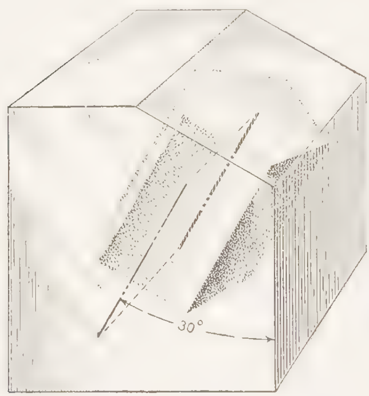


Fig. 2

PROBLEM 4.—The prism shown in Fig. 1 is inclined toward the side plane so that its center line makes an angle of 45° with that plane, in the direction indicated in Fig. 3. The center line is parallel to the front plane. One side of the prism being parallel to the front plane and the side plane being at the right, draw a full view of the bottom end, a front projection, and a side projection.

Locate the vertical axis $2\frac{3}{8}$ inches from the right border line and the intersection of the front trace with the vertical axis 2 inches from the lower border line.

6. When the center line of a solid is inclined to the three principal planes, and the angles that it makes with two of the planes are given, no projection on either one of the three principal planes can be drawn without some preliminary work. The principle involved in this preliminary work will be explained with the aid of Fig. 4.

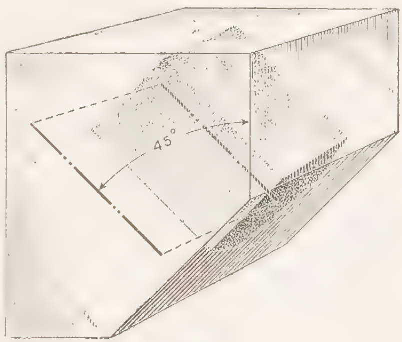


FIG. 3

Let A be a pentagonal prism situated inside of the three principal planes; let $a\,b$ be its center line, which is inclined to the three planes. Let $a'\,b'$ be one of the projections of the center line, in this case the horizontal projection. Imagine an auxiliary plane passing through the center line $a\,b$ and its projection $a'\,b'$; such a plane obviously is perpendicular to the horizontal plane, since it contains the projectors $a\,a'$ and $b\,b'$. Now imagine another auxiliary plane $c\,d\,e\,f$ parallel to the first auxiliary plane; on this plane, since the center line and all side edges of the prism are parallel to it, a true view A' can be projected, with the projection $a_1\,b_1$ of the center line at the given inclination to the horizontal plane. Turn the plane $c\,d\,e\,f$ around its horizontal trace $e\,f$ until it coincides with the horizontal plane, its new position being

indicated by $e f c' d'$. Obviously, the projection $a_2 b_2$ of the center line $a b$ makes the same angle with the trace $e f$ that $a b$ makes with $a' b'$, and since the trace $e f$ is parallel to the projection $a' b'$, the projection $a_2 b_2$ makes the same angle with $a' b'$ that $a b$ makes with $a' b'$. The true view A' takes the position A'' when the auxiliary plane $c d e f$ is turned into the position $c' d' e f$.

Now consider the auxiliary plane $g h i$ parallel to the one end of the prism, on which is projected the full view A_1 of

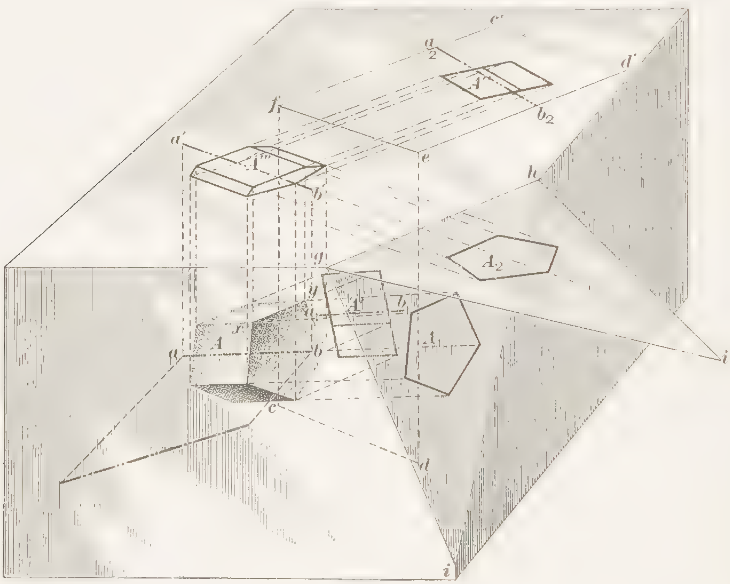
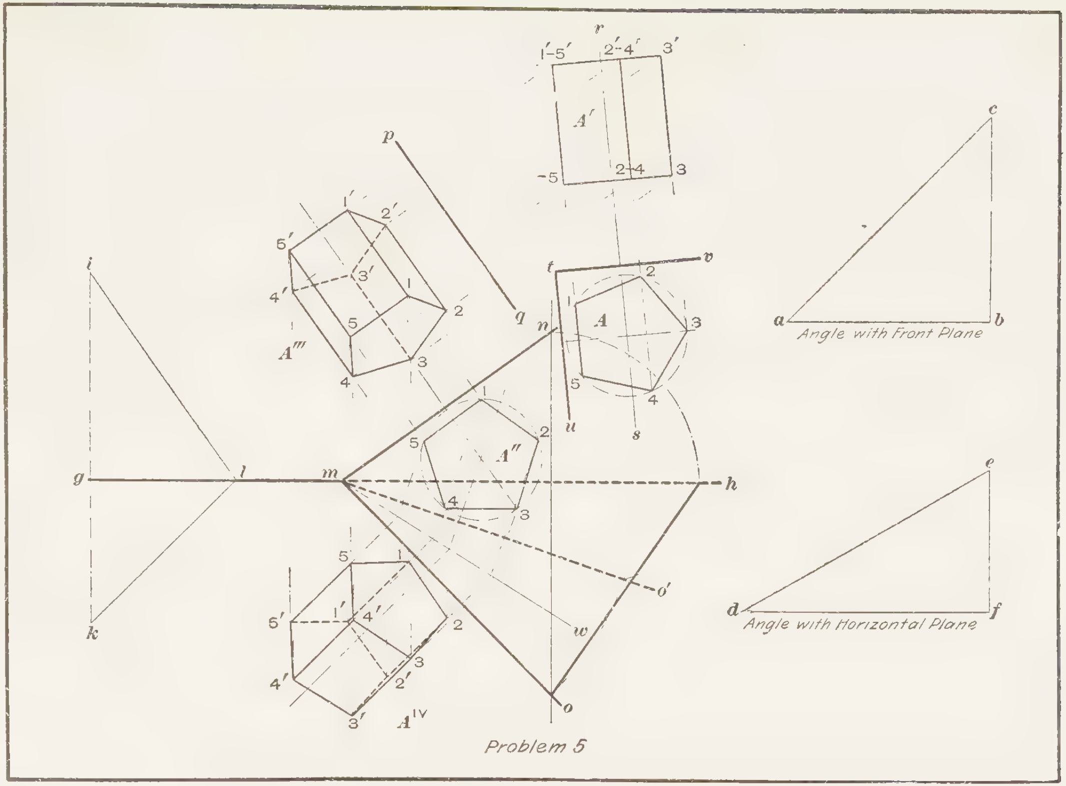


Fig. 4

that end. Turn this auxiliary plane on its horizontal trace $g h$ to the position $g h i'$; that is, level with the horizontal plane, when the full view A_1 assumes the position A_2. Then, on the two auxiliary planes $g h i'$ and $c' d' e f$; which before turning to the level of the horizontal plane were perpendicular to each other, and whose horizontal traces are perpendicular, there are two views of the prism, at right angles to each other. From these two views, A'' and A_2, the horizontal projec-



r
1′-5′
2′-4′
3′
A′
-5
2-4
3
p
q
t
v
A
1
2
3
4
5
u
s
a
b
c
Angle with Front Plane
e
d
f
Angle with Horizontal Plane
A‴
A″
A^IV
i
g
k
l
m
n
h
o′
w
o

Problem 5

tion A''' can be projected, since every point of the prism appears in these two views in correct relation to the horizontal and front planes, as indicated by the projection lines (at right angles to the horizontal traces) drawn from corresponding points of the views A'' and A_2 and intersecting on the horizontal plane.

From the horizontal projection A''' and the full view A_2 the front projection is readily drawn, and from the horizontal and front projections the side projection can be projected, point by point.

7. Problem 5. Sheet II.—The center line of the prism shown in Fig. 1 is inclined to the three principal planes, making an angle of 45° with the front plane and 30° with the horizontal plane, in the directions indicated in Fig. 5.

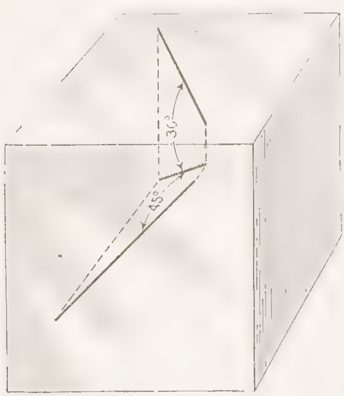


Fig. 5

Draw a horizontal and front projection of the prism, the uppermost edge $x\,y$ of the prism being parallel to the horizontal plane, as shown in Fig. 4.

Solution. — The first and obvious step in the solution of Problem 5 is to find the projections of the center line on the horizontal and front planes.

Draw a right-angled triangle $a\,b\,c$ (see the reduced copy of Sheet II, Exercise I), making the angle $b\,a\,c$ 45° and the hypotenuse $a\,c$ any convenient length, say about 3 inches. Also draw a right-angled triangle $d\,e\,f$, making the angle $e\,d\,f$ 30° and the hypotenuse $d\,e$ exactly equal to $a\,c$.

Draw the horizontal axis $g\,h$ in any convenient location, say $3\frac{1}{8}$ inches from the lower border line. In any convenient place, say $\frac{7}{8}$ inch from the left border line, draw a perpendicular to $g\,h$ and on it lay off $g\,i = b\,c$, and $g\,k = e\,f$. From i as a center and with $d\,f$ as a radius, describe a short arc (not shown) intersecting the horizontal axis at l. Draw the

straight lines $i\,l$ and $k\,l$, which are horizontal and front projections of a straight line intersecting the horizontal axis and making an angle of 45° with the front plane and of 30° with the horizontal plane. As a test of the accuracy of the work see whether $k\,l = a\,b$, as it should. The horizontal projection of the center line of the prism should now be drawn parallel to $i\,l$, and wherever convenient; it may be

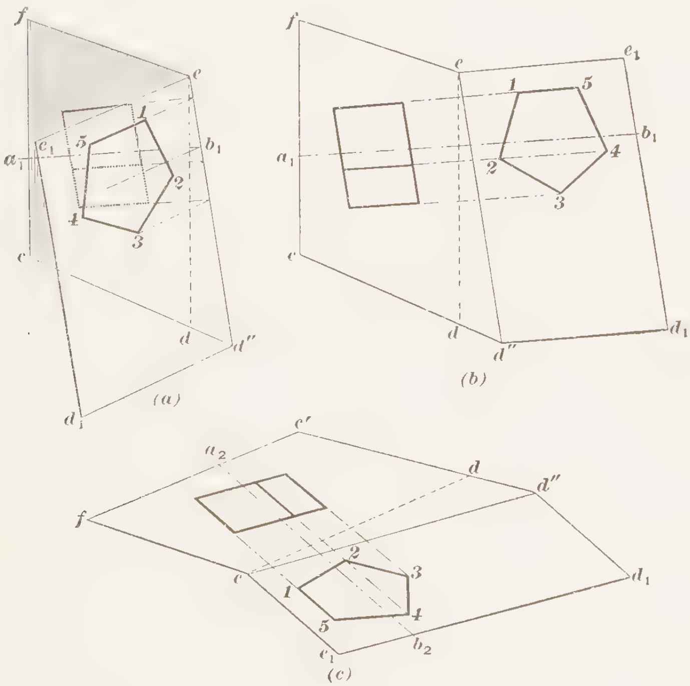


Fig. 6

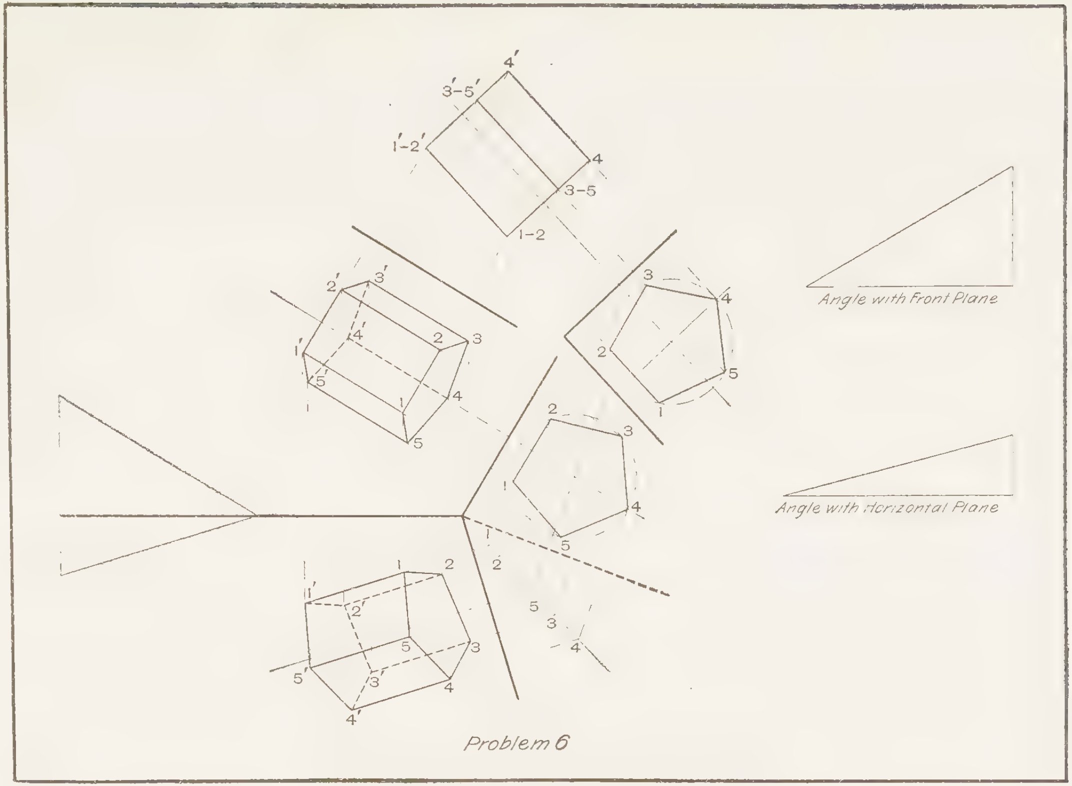
drawn through a point on the horizontal axis $5\frac{1}{8}$ inches from the left border line. Since the ends of the prism are in a plane perpendicular to the center line, the traces of that plane, and hence of any auxiliary plane parallel to it, are perpendicular to the projections of the center line. Draw the horizontal trace $m\,n$ at right angles to the horizontal projection of the center line, locating m $3\frac{1}{2}$ inches from the

left border line. Draw the front trace $m\,o$ at right angles to $k\,l$; also draw the revolved front trace $m\,o'$.

At any convenient distance, say $1\frac{3}{16}$ inches, from the horizontal projection of the center line of the prism, draw parallel to this projection the horizontal trace $p\,q$ of an auxiliary plane; at any convenient distance from the trace $p\,q$ and making an angle of 30° with it, draw a center line $r\,s$. On this center line, in any convenient position, draw an end view A of the prism in such a manner that one edge, as *1–5*, will be parallel to the horizontal plane. Such an end view is located on a plane at right angles to the center line $r\,s$, corresponding to $a_2\,b_2$ in Fig. 4.

Consider Fig. 6 (*a*). In this illustration is shown the auxiliary plane $c\,d\,e\,f$ of Fig. 4, the line $e\,f$ being its horizontal trace. An auxiliary plane at right angles to the center line $a_1\,b_1$ is shown by the outline $e\,e_1\,d_1\,d''$, on which is located an end view of the pentagonal prism; the horizontal trace $e\,e_1$ of the plane containing the end view is at right angles to the axis $e\,d''$ of the two auxiliary planes. Since this axis is at right angles to the center line $a_1\,b_1$, it follows that when the plane containing the end view is turned on the axis $e\,d''$ even with the plane containing the side view, as shown in Fig. 6 (*b*), its revolved horizontal trace $e\,e_1$ will be parallel to the center line $a_1\,b_1$. Now turn the two auxiliary planes from the vertical position in which they were shown in Fig. 6 (*b*), around the horizontal trace $e\,f$, to the level of the horizontal plane, as shown in Fig. 6 (*c*). The new position of the center line is indicated by the letters $a_2\,b_2$ (see also Fig. 4), and the horizontal trace $e\,e_1$, in its second revolved position, is still parallel to the center line. Consequently, if one side of the end view A, referring now to the reduced copy of Sheet II, Exercise I, is drawn parallel to the horizontal trace $t\,u$, corresponding to $e\,e_1$ of Fig. 6, it will insure that the corresponding edge of the prism will be parallel to the horizontal plane. On the same sheet the line $t\,v$ corresponds to the axis $e\,d''$ of Fig. 6.

The end view A (see the reduced copy of Sheet II, Exercise I) having been drawn, the side view A' can be projected.



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It is well to mark by corresponding figures corresponding points of the two views, distinguishing the same points at the second end of the prism by annexing a prime (′) mark, or in some similar manner.

On the horizontal projection of the center line of the prism, produced past the trace *m n* into the auxiliary plane, and at any convenient distance from the trace *m n*, draw a full view A'' of one end of the prism with one side, as *1–5*, parallel to the trace, and number the corners to correspond with those of the end view *A*. From the side view A' and the end view A'', project the horizontal projection A''', point by point. From the horizontal projection A''' and full view A'', project the front projection A^{iv} of the prism.

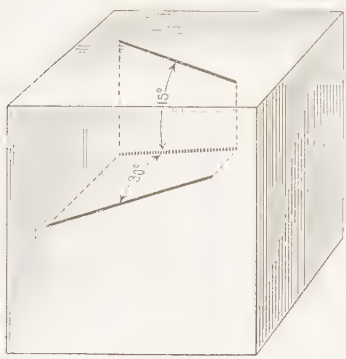
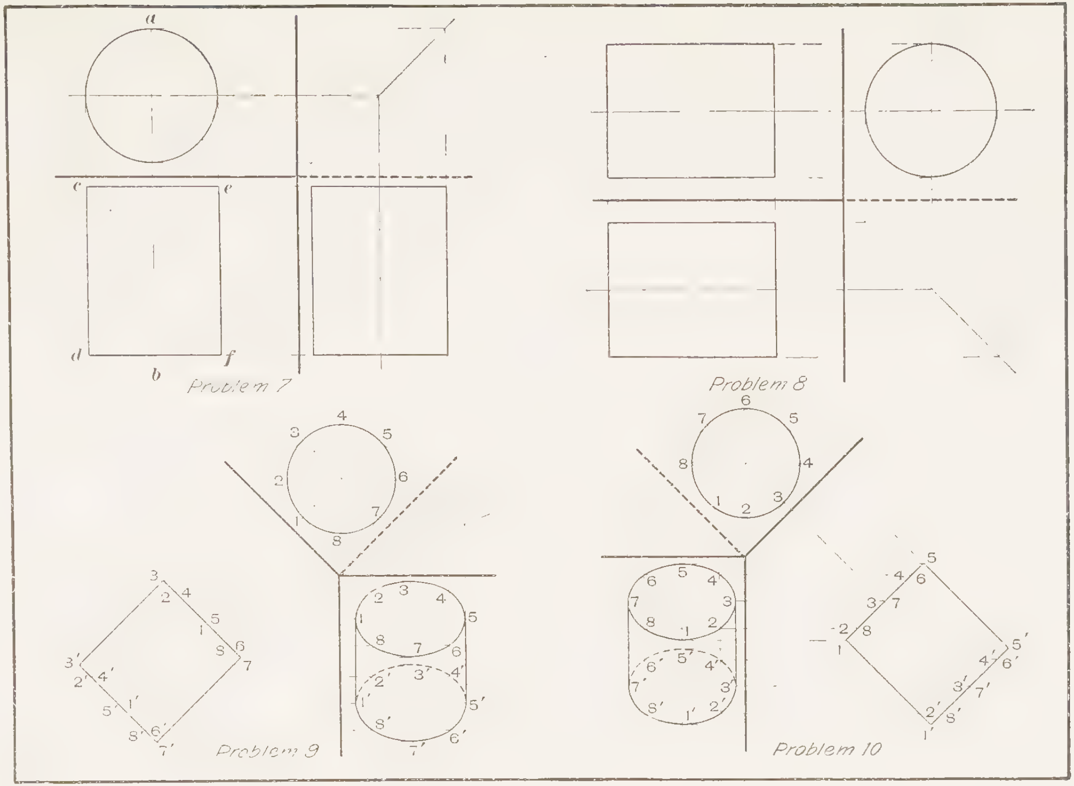


Fig. 7

Referring to the reduced copy of Sheet II, it will be noticed that in transferring to the front trace *m o*, the distances from the point *m* at which projection lines drawn from the corners *1* to *5* intersect the revolved front trace *m o′*, arcs have not been drawn with *m* as a center, as has been done heretofore in similar cases. Instead, the angle *o m o′* has been bisected by the line *m w* and the projection lines extended beyond the revolved front trace *m o′* until they intersect the bisecting line *m w*. From these points of intersection, projection lines perpendicular to the front trace *m o* are drawn into the front plane. This method of transferring intersections obviates the use of compasses, and for this reason is often handier than the arc method; it may also be employed for transferring distances from the origin of the axes of planes from one axis to another.

8. Problem 6. Sheet III.—The center line of the prism shown in Fig. 1 is inclined to the three principal planes,



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making an angle of 30° with the front plane and of 15° with the horizontal plane, in the directions indicated in Fig. 7. The uppermost edge of the prism being parallel to the horizontal plane, as shown in Fig. 4, draw a horizontal and front projection of the prism.

Locate the horizontal axis $2\frac{3}{4}$ inches from the lower border line and the intersection of the traces with the axis $4\frac{11}{16}$ inches from the left border line.

PROJECTION OF SOLIDS BOUNDED BY PLANE AND CURVED SURFACES

EXERCISE II

9. Problem 7. Sheet I.—Draw horizontal, front, and side projections of a cylinder having a diameter of $1\frac{3}{8}$ inches and a height of $1\frac{3}{4}$ inches. The center line of the cylinder is parallel to the front and side planes; the side plane is at the right of the front plane.

Solution.—Referring to the reduced copy of Sheet I, Exercise II, draw the horizontal axis $1\frac{3}{4}$ inches from the upper border line and the vertical and side axes 3 inches from the left border line. Draw the center line *a b* at any convenient distance, say $1\frac{1}{2}$ inches, from the vertical and side axes. Since the ends of the cylinder are parallel to the horizontal plane, the horizontal projection is a circle having a diameter of $1\frac{3}{8}$ inches. For the front projection, draw two straight lines $1\frac{3}{4}$ inches apart and parallel to the horizontal axis. From the horizontal projection, tangent to the circle, project the straight lines *c d* and *e f*; the rectangle *c d f e* is the required front projection. From the horizontal and front projection, project the side projection.

Problem 8.—Draw horizontal, front, and side projections of a cylinder having a diameter of $1\frac{3}{8}$ inches and a height of $1\frac{3}{4}$ inches, the center line of the cylinder being parallel to the horizontal and front planes, and the side plane being at the right of the horizontal plane.

Locate the horizontal axis 2 inches from the upper border line and the vertical and side axes $2\frac{5}{16}$ inches from the right border line.

PROBLEM 9.—The center line of a cylinder having a diameter of $1\frac{1}{8}$ inches and a length of $1\frac{1}{4}$ inches is inclined 45° to the side plane and is parallel to the front plane, the direction in which the center line is inclined being indicated in Fig. 8. The side plane being at the right, draw front and side projections of the cylinder.

SOLUTION.—Referring to the reduced copy of Sheet I, Exercise II, in any convenient location, say $3\frac{3}{8}$ inches from the left border line, draw the vertical axis. From a point on the vertical axis about $2\frac{1}{8}$ inches above the lower border line, draw the front trace of the auxiliary plane on which a full end view is located; this will make an angle of $45+90=135°$ with the vertical axis. At right angles to the vertical axis, draw the side trace, and at right angles to the front trace draw the revolved side trace. At any convenient distance from the intersection of the front trace with the vertical axis, say $\frac{11}{16}$ inch, draw the front projection of the center line; since the center line is parallel to the front plane, its front projection makes the same angle with the vertical axis that the line itself makes with the side plane. On the auxiliary plane draw the end view of the cylinder, which is a circle $1\frac{1}{8}$ inches in diameter; draw the front view, locating the upper end about $1\frac{5}{16}$ inches from the front trace. Divide the end view into any convenient number of parts, say eight, and project these points of division to the front projection. Project the points of division from the full view and the front projection to the side plane, and through their projections on that plane draw the two ellipses forming the side view of the

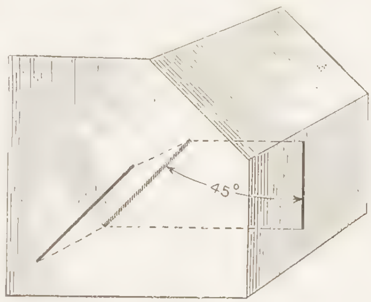


FIG. 8

two ends. Since only the lower half of the lower end is visible, it should be drawn as a full line; the upper half, being hidden from view, is drawn as a dotted line. Draw the straight lines *1–1′* and *5–5′*, which completes the side view.

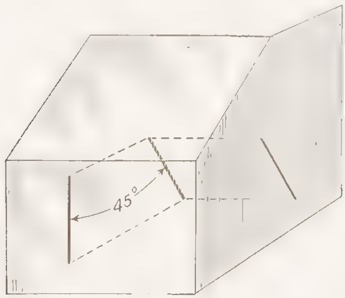


Fig. 9

Problem 10.—The center of the cylinder in Problem 9 is inclined 45° to the front plane, in the direction shown in Fig. 9, and is parallel to the side plane. Draw front and side views of the cylinder, the side plane being at the right of the front plane.

Locate the vertical axis $3\frac{3}{8}$ inches from the right border line and the intersection of the front trace with the vertical axis $2\frac{5}{16}$ inches from the lower border line.

10. Problem 11. Sheet II.—The center line of a cylinder having a diameter of $1\frac{1}{4}$ inches and a length of $1\frac{1}{4}$ inches, is inclined 30° to both the horizontal and front planes, as shown in Fig. 10. Draw a horizontal and front projection of the cylinder.

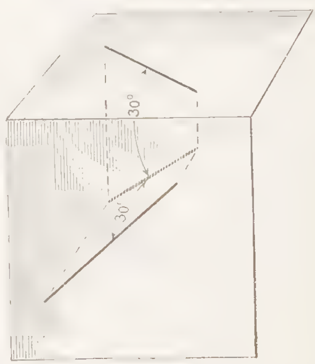


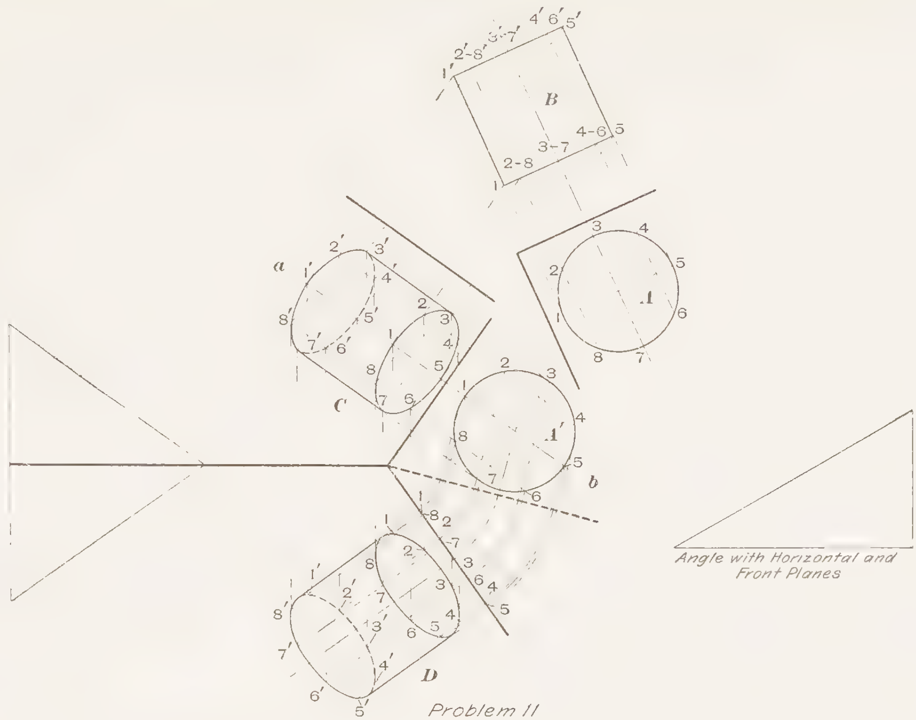
Fig. 10

Solution.—The preliminary work for the solution of this problem is exactly the same as that for the solution of Problems 5 and 6, Exercise I. Referring to the reduced copy of Sheet II, Exercise II, draw the horizontal axis 3 inches from the lower border line and locate the intersection of the traces with that axis $4\frac{7}{16}$ inches from the left border line. Draw the projection *a b* of the center line so that it intersects the horizontal trace $1\frac{1}{16}$ inches from the horizontal axis. Draw the full end view *A* and the side view *B*, divide the circle *A*

Exercise II

Practical Projection, Part 4

Sheet II



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into any convenient number of parts (eight in this instance), and project the points of division *1* to *8* to the side view *B*. Draw the full end view *A′* on its auxiliary plane and establish on it the same points of division that were established on the view *A* and in exactly the same position in reference to the horizontal plane. An easy way of insuring the same relative position of the points of division in the views *A* and *A′* is to begin the division at *1* on a line *1–5* passing through the center of the circle *A* and at right angles to the horizontal trace of its plane; in the view *A′*, begin the division at the point *1* where the center line *a b*, which is at right angles to the horizontal trace of the plane on which *A′* is situated, intersects the circle. From the views *A′* and *B* project the points *1* to *8* and *1′* to *8′* into the horizontal plane; through the points thus found draw ellipses and join *3* and *3′* as well as *7* and *7′* by straight lines, thus completing the required horizontal projection *C*.

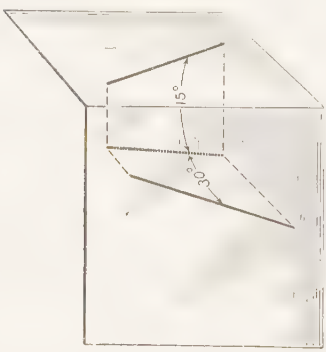
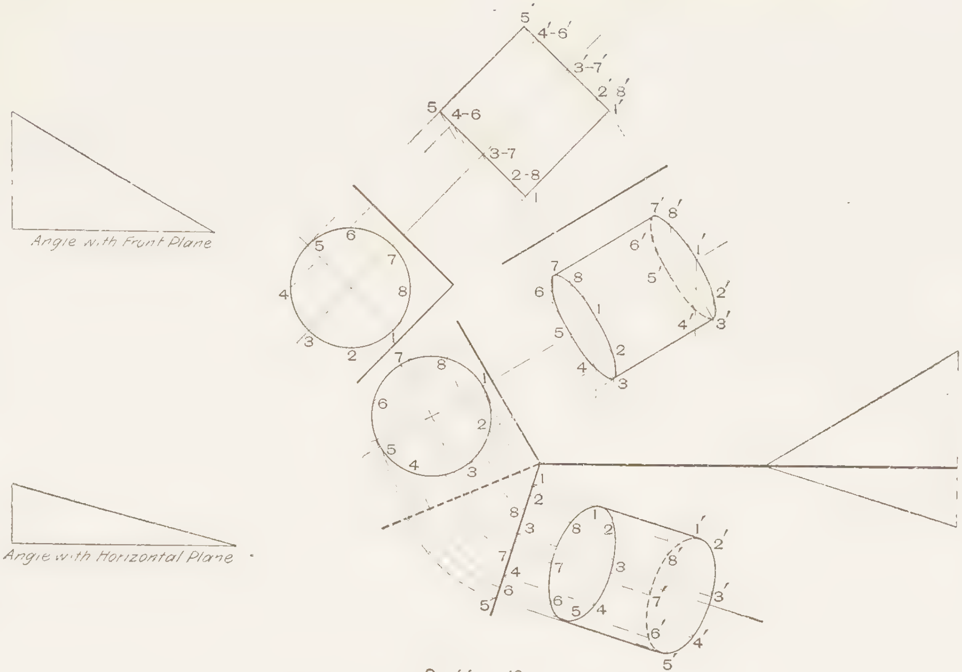


Fig. 11

From the horizontal projection *C* and view *A′*, the front projection *D* is readily projected. It will be observed that none of the points of division in the view *A′* are in a line passing through the center of the circle and parallel to the revolved front trace, and hence in the front view the diameter of the cylinder cannot be obtained by projecting from two of the points of division *1* to *8* of the view *A′*. To obtain the correct diameter of the cylinder in the front projection, draw projection lines tangent to the circle *A′* and perpendicular to the revolved front trace.

11. Problem 12. Sheet III.—The center line of a cylinder $1\frac{1}{4}$ inches in diameter and $1\frac{1}{4}$ inches long is inclined 30° to the front plane and 15° to the horizontal plane, in the directions shown in Fig. 11. Draw the horizontal and front projections of the cylinder.



Problem 12

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Locate the horizontal axis $2\frac{3}{4}$ inches from the lower border line and the intersection of the traces with that axis $4\frac{7}{8}$ inches from the right border line. Make the horizontal projection of the center line intersect the horizontal trace 1 inch from the horizontal axis.

PRACTICAL PROJECTION
(PART 5)

PROJECTION OF SECTIONS

SECTIONS PERPENDICULAR TO ONE PRINCIPAL PLANE

EXERCISE I

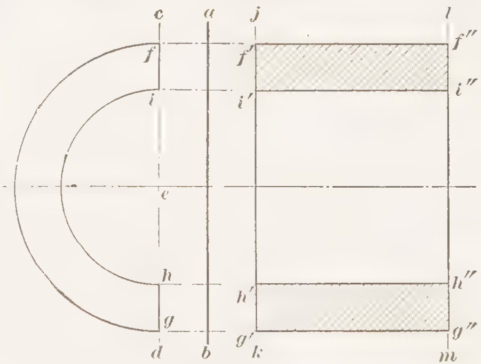
1. In drawing a sectional view of a solid, the method of procedure depends on the position of the cutting plane in reference to that of the three principal planes. Broadly speaking, there are three positions that the cutting plane may occupy. These are:

1. Parallel to one of the three principal planes and perpendicular to the other two. In this case there are two traces, each of which is parallel to an axis.

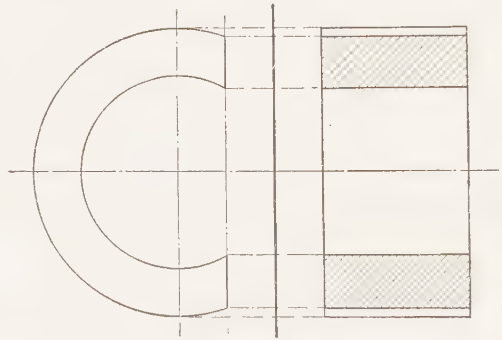
2. Inclined to two of the principal planes and perpendicular to the third. In this case it is possible to have three traces, two of which are parallel to the same axis, and the third is inclined to the other two axes.

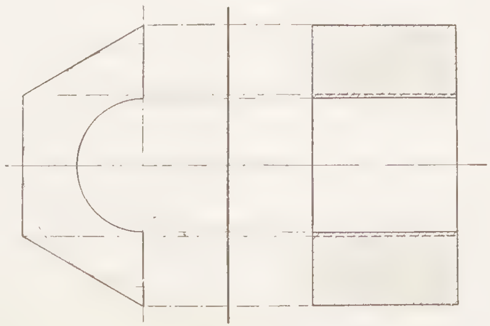
3. Inclined to the three principal planes. All three traces possible are then inclined to the three axes.

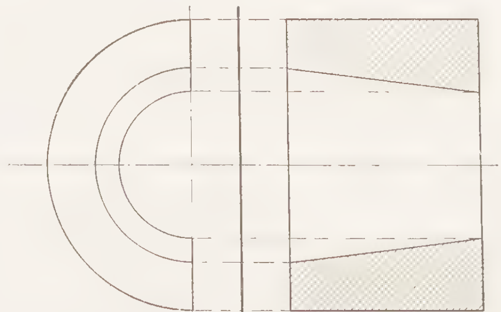
In all cases the projection is begun by drawing those views that are located on the principal planes intersected by the cutting plane; in case of very simple objects the cutting plane may intersect only one of the principal planes, in which case the projection would be begun by drawing the view on that principal plane. From the view on a single principal plane,



Problem 1


Problem 2


Problem 3


Problem 4

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or the views on several principal planes, and the intersection of the cutting plane with the object, as shown on the view or views on principal planes, the sectional view is drawn.

In practice, it is usually desirable that the sectional view show in their true lengths all lines lying in the cutting plane; when such a sectional view is desired, it is obtained by drawing it on a plane parallel to the cutting plane and turned on one of its traces to the level of the drawing.

In case the cutting plane is not parallel to the plane on which the sectional view is shown, some or all of the lines of the sectional view will appear foreshortened; a full view showing all lines of the section in their true lengths is readily drawn by one of the three methods previously given for finding full views of surfaces inclined to the principal planes.

2. Problem 1. Sheet I.—Draw a front view and a sectional side view of a hollow cylinder having an outside diameter of 3 inches, an inside diameter of 2 inches, and a length of 2 inches. The two ends of the cylinder are in planes at right angles to the center line. The cutting plane, as indicated in Fig. 1, passes through the center line of the cylinder and is parallel to the side plane, which is at the right of the front plane. The center line of the cylinder is at right angles to the front plane.

Solution.—Referring to the reduced copy of Sheet I, Exercise I, in any convenient location, say $2\frac{1}{2}$ inches from the left border line, draw the vertical axis $a\,b$. Since the cutting plane is parallel to the side plane, its front trace is parallel to the vertical axis; since the distance of the cutting plane from the side plane is not given, draw the front trace $c\,d$ at any convenient distance, say $\frac{1}{2}$ inch, from the vertical axis. On the front trace locate the front projection e of the center line of the cylinder; since the center line is at right angles to the front plane, its front projection is a point. This front projection e may be located 2 inches from the upper border line. With e as a center and radii of $3 \div 2 = 1\frac{1}{2}$ inches, and $2 \div 2 = 1$ inch, respectively, describe the semicircles $f\,g$ and $h\,i$; the outline $f\,i\,h\,g$ is the required front projection.

Since the ends of the cylinder are in planes at right angles to the center line, and since this line is at right angles to the front plane, it follows that these planes are parallel to the front plane, and hence their side traces (which contain the side projections of the ends of the cylinder) are parallel to the vertical axis. The distance of the cylinder from the front plane not being given, draw the trace $j\,k$ at any convenient distance from the vertical axis, say $\frac{1}{2}$ inch. At a distance equal to the length of the cylinder, or 2 inches, from the trace $j\,k$ draw the trace $l\,m$. Project the points f, i, h, g on the traces $j\,k$ and $l\,m$. Now draw the outline $f'\,i'\,h'\,g'\,g''\,h''\,i''\,f''$, which is the required sectional view. Cross-section

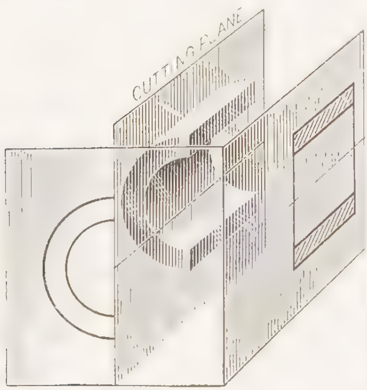


FIG. 1

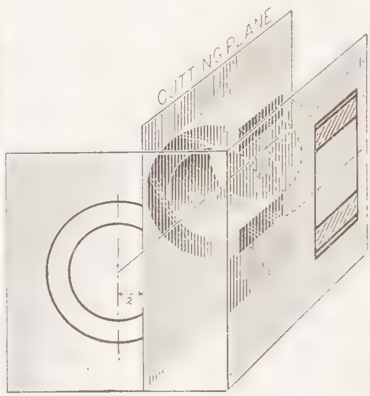


FIG. 2

$f'\,i'\,i''\,f''$ and $h'\,g'\,g''\,h''$ to indicate that these two parts were cut by a cutting plane, or are *in section*, as it is called.

PROBLEM 2.—Draw a front and a sectional side view of a cylinder having an outside diameter of 3 inches, an inside diameter of 2 inches, and a length of $1\frac{1}{2}$ inches. The center line of the cylinder is perpendicular to the front plane. The cutting plane is perpendicular to the front plane and parallel to the side plane, which is at the right. The cutting plane, as shown in Fig. 2, passes through the cylinder at a distance of $\frac{1}{2}$ inch to the right of the center line. The end surfaces of the cylinder are at right angles to its axis.

Locate the vertical axis $2\frac{1}{2}$ inches from the right border line; locate the center line of the cylinder 2 inches from the upper border line; locate the front trace of the cutting plane $\frac{1}{2}$ inch from the vertical axis; and locate the front end of the cylinder $\frac{1}{2}$ inch from the front plane.

PROBLEM 3.—Draw a front and a sectional side view of a hexagonal prism circumscribing a cylinder having a diameter of $2\frac{1}{2}$ inches. The prism has a central hole $1\frac{3}{8}$ inches in diameter and a height of $1\frac{1}{2}$ inches. The center line of the prism is perpendicular to the front plane; the cutting plane, as shown in Fig. 3, passes through the center line of the prism

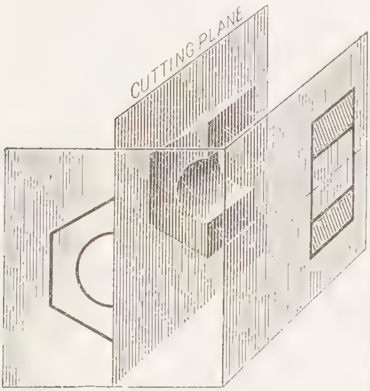


FIG. 3

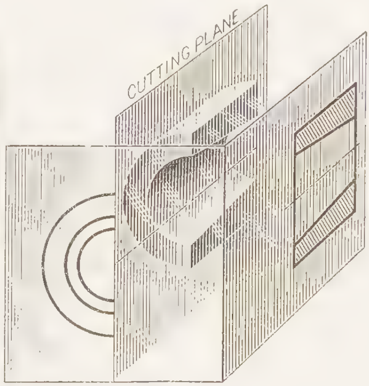


FIG. 4

and is parallel to the side plane, which is at the right. One of the sides of the prism is parallel to the side plane. The ends of the prism are at right angles to its center line.

Locate the vertical axis $2\frac{5}{8}$ inches from the left border line and the center line of the prism 2 inches from the lower border line. Draw the front trace of the cutting plane $\frac{7}{8}$ inch from the vertical axis, and assume that the front end of the prism is $\frac{7}{8}$ inch from the front plane.

PROBLEM 4.—Draw a front and a sectional side view, the side plane being on the right, of a hollow cylinder having an outside diameter of 3 inches and a length of 2 inches.

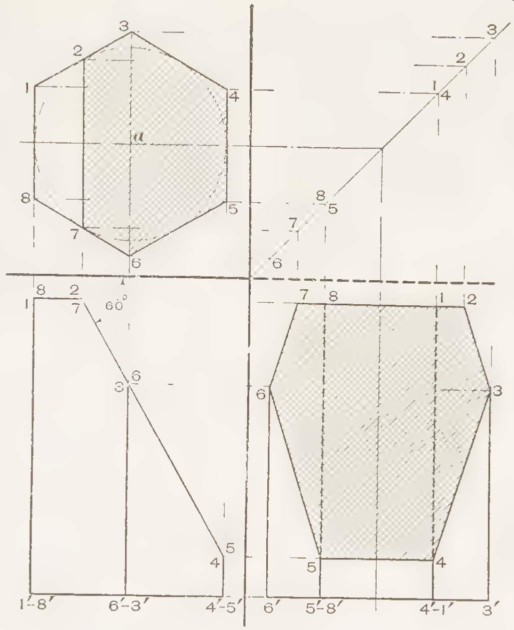
The central hole is tapering, having a diameter of 2 inches at one end and of $1\frac{1}{2}$ inches at the opposite end of the cylinder. The center line of the cylinder is perpendicular to the front plane; the cutting plane, as shown in Fig. 4, passes through the center line of the cylinder and is parallel to the side plane. The ends of the cylinder are at right angles to the center line, and the large end of the hole is toward the front plane.

Locate the vertical axis 3 inches from the right border line and the center line of the cylinder 2 inches from the lower border line. Draw the front trace of the cutting plane $\frac{1}{2}$ inch from the vertical axis and assume that the front end of the cylinder is $\frac{1}{2}$ inch from the front plane.

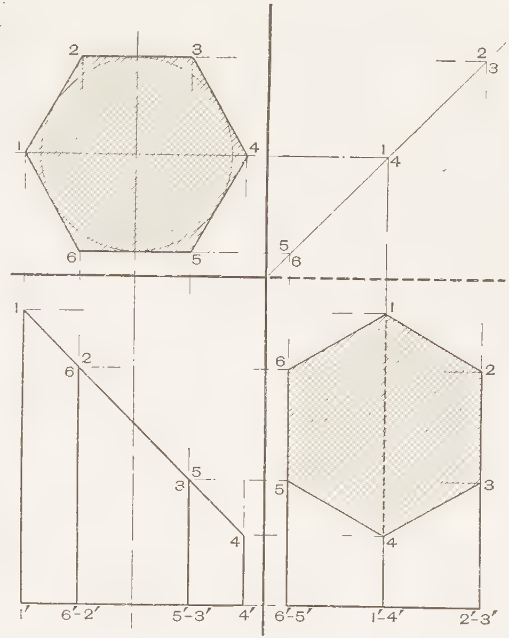
3. Practice varies somewhat in regard to drawing the view on that plane on which is shown the trace of the cutting plane; this plane, in Problems 1 to 4, inclusive, was the front plane. In the case of objects symmetrical in respect to their center line, it is the most common practice not to show those portions of the solid that were assumed to be removed, as was done in the solution presented on the reduced copy of Sheet I, Exercise I. When the view on that plane on which is shown a trace of a cutting plane is unsymmetrical in respect to its center line, it is usually advisable to show the complete view.

It will be understood that in making a sectional drawing the lines composing the outline of the section at the cutting plane will show in their true lengths only when the cutting plane is parallel to the plane on which the sectional view is drawn.

4. PROBLEM 5. Sheet II.—A regular hexagonal prism circumscribing a circle 2 inches in diameter has its center line perpendicular to the horizontal plane and two opposite sides parallel to the side plane, which is at the right of the front plane. The ends of the prism are at right angles to its center line; the prism is $3\frac{1}{16}$ inches high. A cutting plane perpendicular to the front plane and making an angle of 60° with the horizontal plane passes through the prism in such a position that, as shown in Fig. 5, it intersects the top of



Problem 5



Problem 6

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the prism $\frac{1}{2}$ inch from the edge farthest from the side plane. Draw a top, a front, and a side view.

SOLUTION.—Referring to the reduced copy of Sheet II, Exercise I, in any convenient location, say $3\frac{5}{8}$ inches from the upper border line, draw the horizontal and revolved side axes; in any convenient place, say $2\frac{3}{4}$ inches from the left border line, draw the vertical and side axes. Since the prism is not definitely located in reference to the principal planes, the views may occupy any convenient position provided they are drawn in true relation to each other. The first view to be drawn is the top view. On the horizontal plane, choose the point *a* where the center line pierces the plane; it is

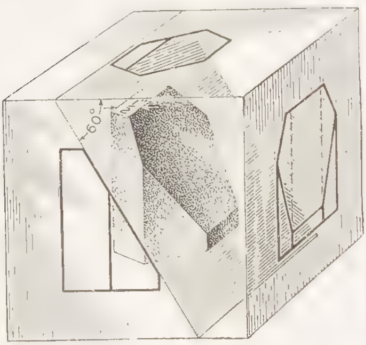


FIG. 5

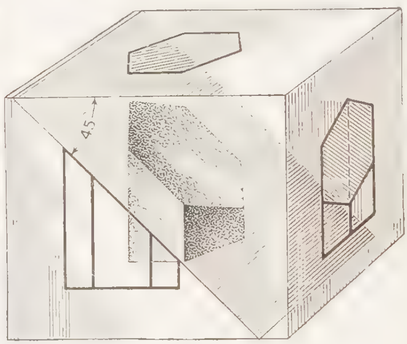


FIG. 6

suggested that it be located $1\frac{1}{4}$ inches from the side axis and $1\frac{3}{8}$ inches from the horizontal axis. Draw a circle 2 inches in diameter with *a* as a center and construct the top view, being careful to have the edges *1–8* and *4–5* parallel to the side axis. Since the ends of the prism are parallel to the horizontal plane and the cutting plane is perpendicular to the front plane, the intersection of the cutting plane with the upper end of the prism is parallel to both the horizontal and the side plane. Consequently, the horizontal projection of this line of intersection is parallel to the side axis. Therefore, at a distance of $\frac{1}{2}$ inch from the edge *1–8* of the top view and parallel to the side axis draw the line *2–7*, which is the

projection of the line of intersection of the cutting plane with the upper end of the prism.

Next, draw the front view, projecting the different corners downwards from the plan view and make the prism $3\frac{1}{16}$ inches high, locating the top of the prism at some convenient distance, say $\frac{1}{4}$ inch, from the horizontal axis. Project the line *2–7* of the top view on the line denoting the upper end of the prism in the front view; through the point of intersection draw a line at an angle of 60° with the horizontal axis, in the direction shown by Fig. 5, which line is the front trace of the cutting plane.

Now, from the top and front views, project the side view. In the top and side views, cross-section the prism where it is cut by the cutting plane; this completes the solution.

Problem 6.—The same prism that was given in Problem 5 has its center line perpendicular to the horizontal plane and occupies a position in which two opposite sides, as shown in Fig. 6, are parallel to the front plane. A cutting plane making an angle of 45° with the horizontal plane, and which is perpendicular to the front plane, passes through the upper corner, farthest from the side plane, of the prism. The side plane being at the right of the front plane, draw a top, a front, and a side view.

Locate the horizontal axis $3\frac{1}{2}$ inches from the upper border line and the vertical axis $2\frac{3}{4}$ inches from the right border line. Locate the center line on the horizontal plane $1\frac{1}{4}$ inches from the horizontal axis and $1\frac{3}{8}$ inches from the side axis. In the front view, locate the highest corner $\frac{3}{8}$ inch from the horizontal axis.

SECTIONS OBLIQUE TO THREE PRINCIPAL PLANES

EXERCISE II

5. Before projection drawings of a section cut by a cutting plane inclined to the three principal planes can be made on the actual drawing, it is necessary to find from the known

angles the traces either of the cutting plane or of some convenient auxiliary plane parallel to the cutting plane.

The principle involved in finding the traces of a plane inclined to the three principal planes from the angles it makes with two of those planes cannot be readily made clear by illustrations. There is, however, a simple and easily remembered general solution, which is here presented without any attempt being made to explain the principle involved.

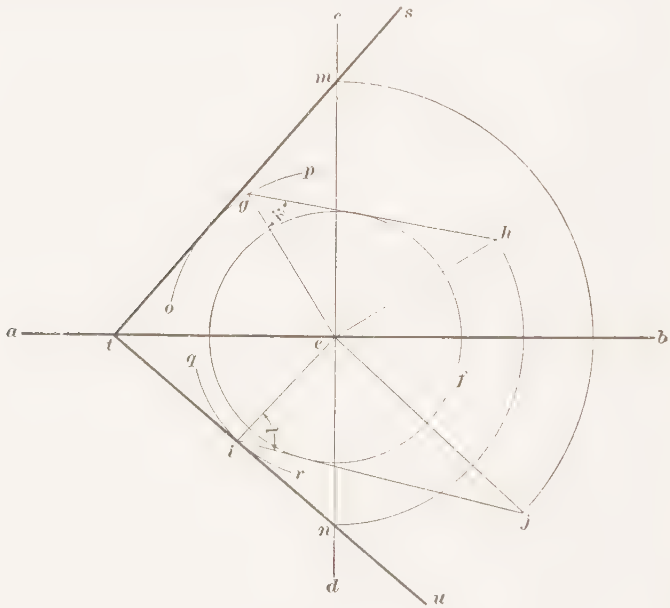


FIG. 7

Referring to Fig. 7, let *a b* be an axis of two of the principal planes. At any convenient point draw a line *c d* perpendicular to the axis *a b*. With the intersection *e* as a center and any convenient radius, describe the circle *f*. On each principal plane and in any convenient direction draw a line, as *g h* and *i j*, tangent to the circle *f* at convenient points. From the center *e* of the circle *f* draw a straight line *e g* to intersect the tangent *g h*, drawing it in such a position that the angle *k* between *e g* and *g h* is equal to the angle

the cutting plane makes with the plane on which the line *g h* is located. Exactly at right angles to *e g*, and from the center *e*, draw the straight line *e h*. Similarly, draw the line *e i* so that the angle *l* between *e i* and *i j* is equal to the angle that the cutting plane makes with the plane on which *i j* is located. Draw *e j* exactly at right angles to *e i*. Next, with *e j* as a radius and *e* as a center, describe an arc intersecting the line *c d* at *m*; also, with *e h* as a radius and *e* as a center, describe an arc intersecting the line *c d* at *n*. With *e g* and *e i* as radii and *e* as a center, describe the arcs *o p* and *q r*. Through the points *m* and *n* draw the straight lines *s t* and *u t* tangent to the arcs *o p* and *q r*; these two lines are the required two traces.

If the work has been accurately done, the traces intersect on the axis *a b*; if the traces should fail to intersect exactly on the axis, the drawing must be gone over minutely, step by step, to find the error or errors.

6. In practice, it sometimes occurs that the traces of a cutting plane, or of any other auxiliary plane, inclined to the three principal planes, are known and it is required to find the angle or angles that the plane makes with one or all of the principal planes. The principle involved is shown in Fig. 8.

When two planes intersect, the angle between these two planes is measured on a third plane perpendicular to both intersecting planes. Thus, in Fig. 8 (*a*), the auxiliary plane *a b c* is perpendicular to both the horizontal plane and the auxiliary plane *d e f*, and the angle *g* between the trace *a b* and the line of intersection *a c* is the angle the plane *d e f* makes with the horizontal plane. Since the auxiliary plane *a b c* is perpendicular to the horizontal plane and the auxiliary plane *d e f*, the horizontal trace *a b* is perpendicular to the horizontal trace *d e*; the front trace *b c* is perpendicular to the horizontal axis, and the angle between the horizontal trace *a b* and the front trace *b c* is a right angle. Next, imagine that the auxiliary plane *a b c* is turned on its horizontal trace *a b* into the horizontal plane, as indicated by the triangle *a b c′*, Fig. 8 (*b*). In this triangle, the length of

the side $b\,c'$ obviously is equal to that of the front trace $b\,c$; $b\,c'$ is parallel to the horizontal trace $d\,e$, and the angle g is the angle between the horizontal plane and the plane $d\,e\,f$.

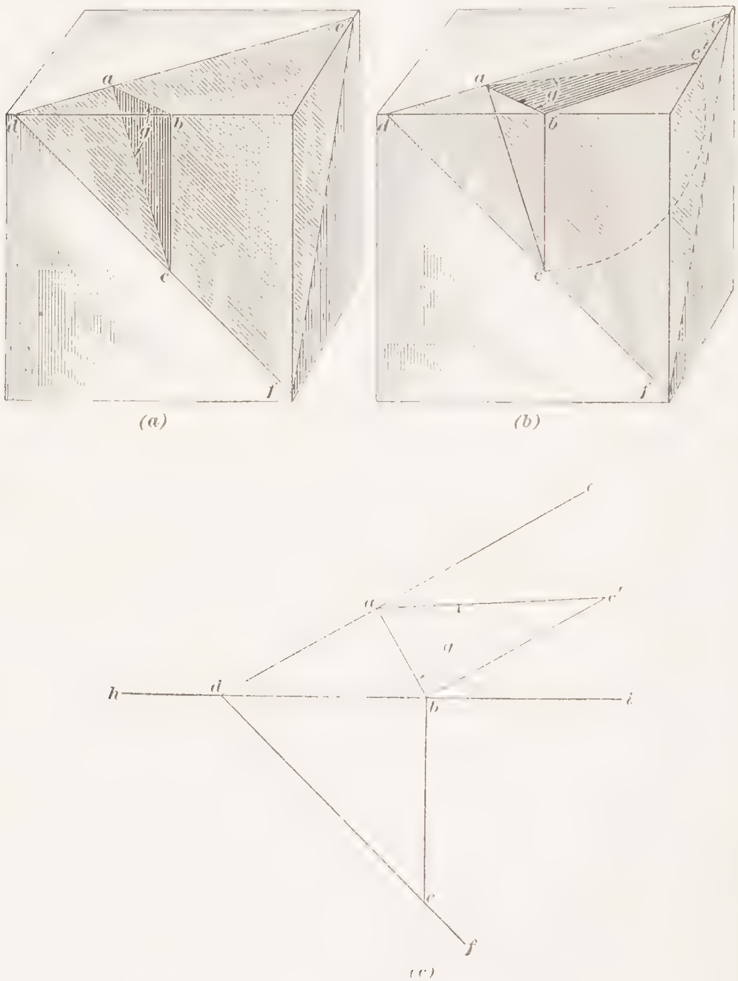


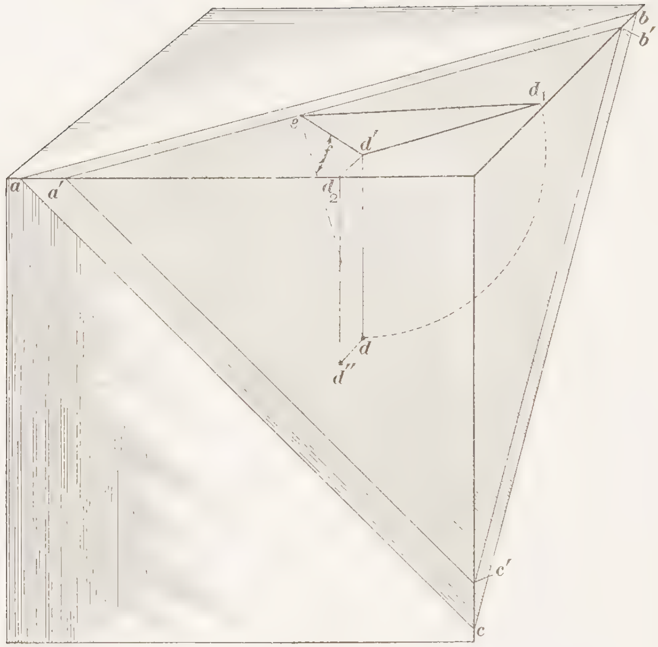
Fig. 8

In Fig. 8 (c), let $d\,e$ be the given horizontal trace and $d\,f$ the given front trace; let $h\,i$ be the horizontal axis. To

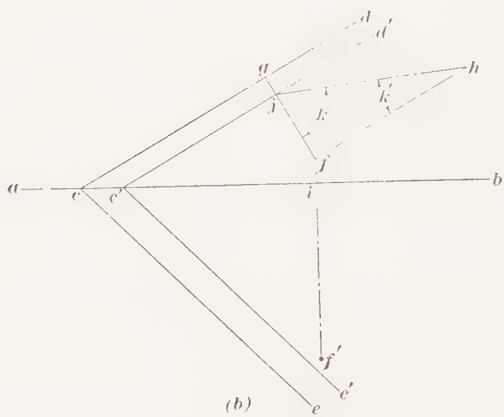
find the angle the auxiliary plane makes with the horizontal plane, at any convenient point on the trace $d\,e$ erect a perpendicular $a\,b$ intersecting the horizontal axis at b. From the point of intersection b draw a line $b\,c$ perpendicular to the horizontal axis $h\,i$ and intersecting the front trace $d\,f$ at c. Through the point of intersection b draw a line $b\,c'$ parallel to the horizontal trace $d\,e$ and make the length of $b\,c'$ equal to that of $b\,c$. Join a and c' by a straight line; the angle g between the lines $a\,b$ and $a\,c'$ is the required angle.

In precisely the same manner the angles the auxiliary plane makes with the front and side planes can be determined.

7. In nearly all cases occurring in practice where projections of a section cut by a cutting plane inclined to the three principal planes are to be drawn, it is required that the cutting plane pass through some given point of the object. The principle involved in doing this is shown in Fig. 9 (a). In this illustration $a\,b$ and $a\,c$ are the horizontal and front traces of a plane $a\,b\,c$ that makes the given angles with the horizontal and front planes. These two traces, on a drawing, are easily found by applying the method given in Art. **5.** Assume d to be a point in space, and let d' be its horizontal projection and d'' its front projection. Let the plane $a'\,b'\,c'$ be parallel to the plane $a\,b\,c$ and pass through the point d. Then, the horizontal trace $a'\,b'$ is parallel to $a\,b$, and the front trace $a'\,c'$ is parallel to $a\,c$. Conceive a triangular plane $d\,d'\,e$, perpendicular to the horizontal plane and to the plane $a'\,b'\,c'$. In this triangular plane the trace $d'\,e$ is at right angles to the trace $a'\,b'$, and hence to the trace $a\,b$; the angle f is the angle the plane $a'\,b'\,c'$ makes with the horizontal plane, and the angle between $e\,d'$ and $d'\,d$ is a right angle. Turn the triangular plane $e\,d'\,d$ on its horizontal trace $e\,d'$ into the horizontal plane, as shown by the outline $e\,d'\,d_1$. In this new position, the side $d'\,d_1$ is parallel to the trace $a'\,b'$ and hence to $a\,b$; its length is equal to that of the projector $d'\,d$, and hence to that of the projection $d''\,d_2$ of the projector $d'\,d$. The angle between $d'\,e$ and $d_1\,e$ is the angle



(a)



(b)

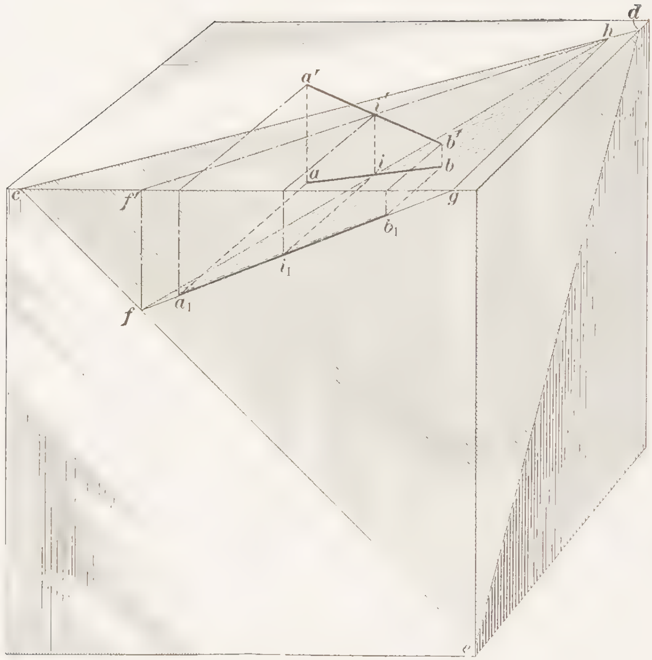
Fig. 9

made by the planes $a\,b\,c$ and $a'\,b'\,c'$ with the horizontal plane, and the angle between $e\,d'$ and $d'\,d_1$ is a right angle.

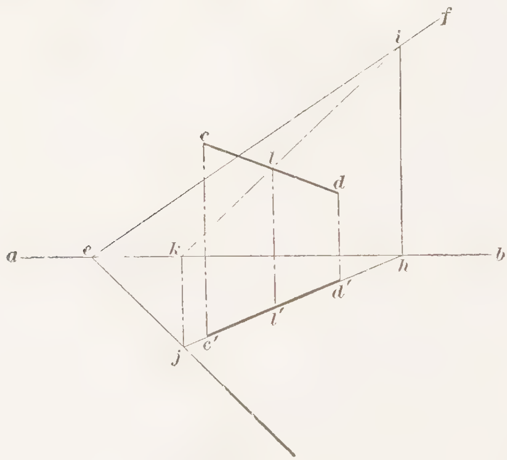
Hence the following construction: In Fig. 9 (b), let $a\,b$ be an axis, and $c\,d$ and $c\,e$ traces of a plane that were determined by the method given in Art. **5.** Let f and f' be two projections of the point through which is to be passed a cutting plane parallel to that given by the traces $c\,d$ and $c\,e$. Through the projection f draw a line $f\,g$ at right angles to the trace $c\,d$, and draw a line $f\,h$ parallel to the trace $c\,d$. Make the length of $f\,h = i\,f'$. Through the point h draw a line $h\,j$ in such a position that the angle k is equal to the angle between the plane on which the trace $c\,d$ is located and the plane defined by the traces $c\,d$ and $c\,e$. This is done in practice by laying off, with h as a vertex, the angle k', which is equal to 90° diminished by the angle k. Through the intersection j of the line $h\,j$ with the line $f\,g$ draw the trace $c'\,d'$ parallel to the trace $c\,d$; through the intersection c' of the trace $c'\,d'$ with the axis $a\,b$ draw the trace $c'\,e'$ parallel to $c\,e$. The traces $c'\,d'$ and $c'\,e'$ are traces of the auxiliary plane making the given angles with the principal planes on which the traces are located, and the auxiliary plane passes through the point in space whose given projections are at f and f'.

8. When a cutting plane inclined to the three principal planes is to be passed through an object bounded by plane surfaces and projection drawings of the section are to be made, it becomes necessary to determine just where each edge of the object is intersected by the cutting plane. In the case of objects not having plane surfaces and no well-defined edges, the intersection of lines, drawn arbitrarily on the surfaces of the body, with the cutting plane must be found.

In practice, the problem, reduced to its simplest form, presents itself thus: Two projections of a line are given as well as the traces of the cutting plane on corresponding principal planes; find the two projections of the point where the line whose projections are given intersects the cutting plane whose traces are given.



(a)

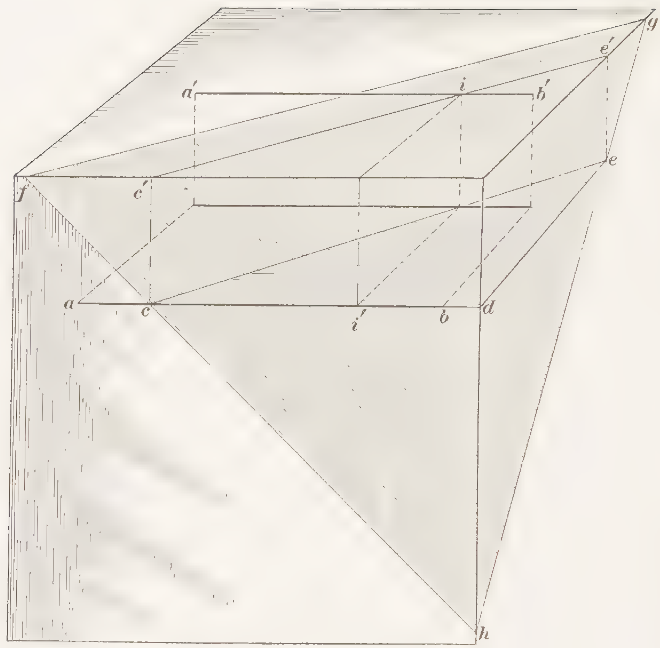


(b)

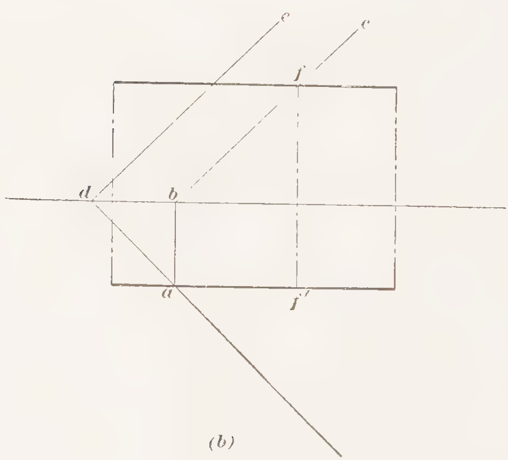
Fig. 10

The principle involved in the solution is illustrated in Fig. 10 (*a*), where $a\,b$ is a straight line whose horizontal projection $a'\,b'$ and front projection $a_1\,b_1$ are given. The plane $c\,d\,e$ is inclined to all three principal planes, as shown. Imagine an auxiliary plane $f\,g\,h$, perpendicular to the front plane, to be passed through the line $a\,b$. The front trace $f\,g$ obviously contains the front projection $a_1\,b_1$. The horizontal trace $g\,h$, since the auxiliary plane $f\,g\,h$ is perpendicular to the front plane, is perpendicular to the horizontal axis. The intersection of the cutting plane $c\,d\,e$ and the auxiliary plane $f\,g\,h$ is obviously the straight line $f\,h$ drawn from the intersection f of the two front traces to the intersection h of the two horizontal traces. Since the line $a\,b$ in space lies partly in the auxiliary plane $f\,g\,h$, it is readily seen that it pierces the cutting plane in a point i situated on the line of intersection $f\,h$ of the two auxiliary planes. The horizontal projection i' of the point i is the intersection of the horizontal projection $f'\,h$ of the line of intersection $f\,h$ with the horizontal projection $a'\,b'$ of the line $a\,b$; the front projection i_1 is the intersection of a plane perpendicular to the horizontal and front planes with the front projection $a_1\,b_1$ of the line $a\,b$.

Hence the following construction: On an actual drawing, the axis $a\,b$ of two principal planes, the projections $c\,d$ and $c'\,d'$, and the traces $e\,f$ and $e\,g$ of a cutting plane are given, as shown in (*b*). To find the projections of the intersection of the line whose projections are given with the plane whose traces are given, produce one of the projections, as $c'\,d'$ for instance, until it intersects the axis $a\,b$ in h, and if necessary also produce it until it intersects the trace $e\,g$ at j. At h, draw a line $h\,i$ perpendicular to the axis $a\,b$ and intersecting the trace $e\,f$ at i. From the intersection j on the trace $e\,g$ draw a line $j\,k$ perpendicular to the axis $a\,b$ and intersecting it in k. Join k and i by a straight line. The intersection l is the one projection of the point where the line whose projections are given pierces the plane whose traces are given; to find the second projection, through the point l draw a line at right angles to the axis $a\,b$ and intersecting the projection $c'\,d'$ at l', which intersection is the required second projection.



(a)



(b)

Fig. 11

9. One of the three extreme cases of finding the intersection of a line in space with an auxiliary or cutting plane inclined to the three principal planes is shown in Fig. 11 (a). Here the line whose two projections are given is parallel to both principal planes. Through one projection, as $a\ b$ for instance, pass an auxiliary plane $c\ d\ e$ perpendicular to the plane on which $a\ b$ is located; this plane $c\ d\ e$ is parallel to the plane on which the projection $a'\ b'$ is located. Consequently, the intersection $c\ e$ is parallel to the trace $f\ g$ and hence the projection $c'\ e'$ of the intersection is also parallel to the trace $f\ g$. The point c' where $c'\ e'$ intersects the axis is the projection of the point c where the trace $c\ d$ intersects the trace $f\ h$. The intersection i between $c'\ e'$ and $a'\ b'$ is the one projection of the point where the line in space intersects the plane whose traces are $f\ g$ and $f\ h$; the second projection is at i'.

Hence the following contruction on the actual drawing: Referring to Fig. 11 (b), from the point a where the one projection (or the one projection produced) intersects the one trace, draw a perpendicular to the axis, intersecting it at b. Through b draw $b\ c$ parallel to the trace $d\ e$. Project the point of intersection f with the given projection of the line to the second given projection; f and f' are the required two projections.

10. The second extreme case of finding the intersection of a line in space with a plane inclined to the three principal planes is presented in Fig. 12 (a). Here the line is parallel to one of the two given principal planes and perpendicular to the other; consequently, one projection is a point and the second projection is a line perpendicular to the axis. Through the line in space pass an auxiliary plane parallel to that principal plane on which the projection of the line in space appears as a line. The trace $a\ b$ obviously passes through that projection of the line which appears as a point. The line in space intersects the plane $d\ e\ f$ in a point on the line of intersection $a\ c$ of the plane $a\ b\ c$ with the plane $d\ e\ f$. Obviously, the intersection g of the projection $a'\ c'$ of $a\ c$

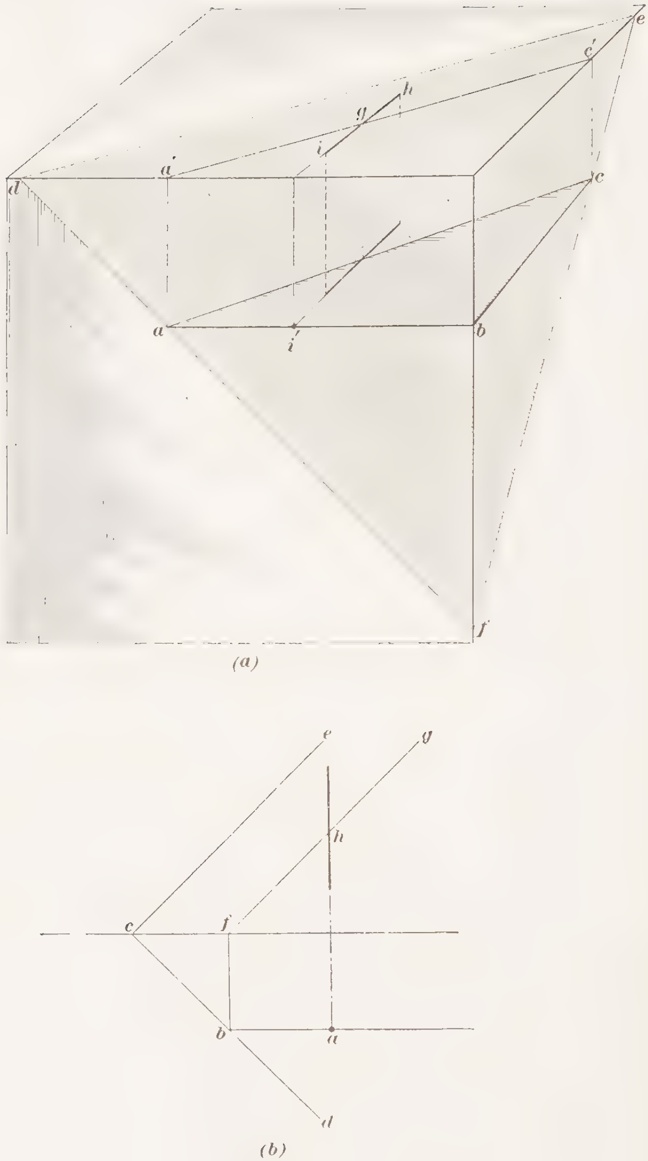


Fig. 12

with the projection $h\ i$ is the one projection of the point where the given line in space intersects the plane $d\ e\ f$; the second projection of that point of intersection coincides with the second projection i' of the line in space, which is a point. Since the plane $a\ b\ c$ is parallel to the principal plane on which appears the projection $h\ i$, the projection $a'\ c'$ of the intersection $a\ c$ is parallel to the trace $d\ e$.

Hence the construction illustrated in Fig. 12 (b). Through the projection a of the given line draw a line $a\ b$ parallel to the axis and intersecting the trace $c\ d$ at b. From the intersection b draw a perpendicular $b\ f$ to the axis. Through f draw the line $f\ g$ parallel to the trace $c\ e$; its intersection h with the projection of the line is the one required projection, the point a being the second one, of the point in space where the given line pierces the plane defined by the traces $c\ d$ and $c\ e$.

11. The third extreme case of finding the intersection of a line in space with a cutting plane or an auxiliary plane inclined to the three planes of projection is presented in Fig. 13 (a). In this case the line is inclined to two, and parallel to the third, of the principal planes, and the two given projections of the line (the horizontal and front projections in this instance) are perpendicular to the axis of the planes on which they are situated (the horizontal axis in this case). In Fig. 13 (a), let $a\ b\ c$ be the cutting plane and let $d\ e\ f$ be an auxiliary plane containing the two given projections $g\ h$ and $g'\ h'$. The point i at which the line in space pierces the plane $a\ b\ c$ is in the line of intersection $e\ f$ of the auxiliary plane $d\ e\ f$ with the plane $a\ b\ c$. Neither the horizontal projection $d\ e$ nor the front projection $d\ f$ of the line of intersection $e\ f$ intersects either the horizontal projection $g\ h$ or the front projection $g'\ h'$ of the given line; they coincide with the projections of the given line. However, if there is a side projection $g_1\ h_1$ of the given line in space, a side projection $e_1\ f_1$ of the line of intersection $e\ f$ will intersect the side projection $g_1\ h_1$ at i_1, which point is a side projection of the point i where the line in space pierces the auxiliary

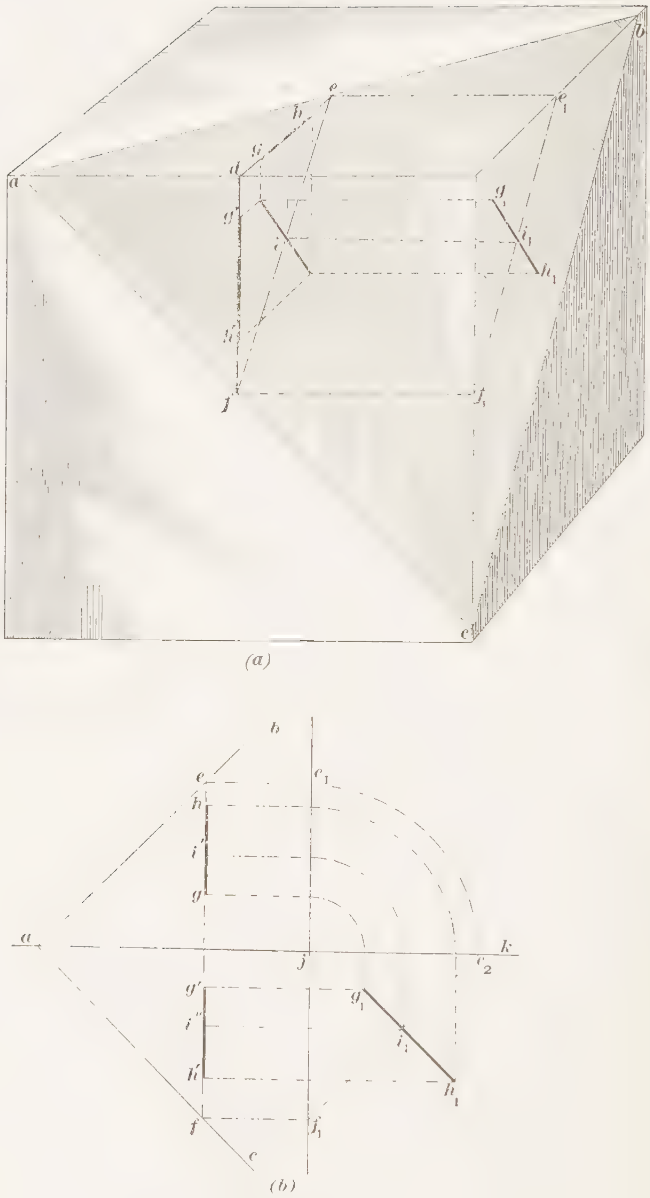


Fig 13

plane $a\,b\,c$. From the side projection i_1 of the point i its horizontal and front projections are easily determined, since it is known that these projections must be on $g\,h$ and $g'\,h'$.

From the foregoing, the construction shown in Fig. 13 (b) should be plain: Produce the projections $g\,h$ and $g'\,h'$ until they intersect the traces $a\,b$ and $a\,c$ in e and f, the third view $g_1\,h_1$ having been previously drawn. Through e and f draw projection lines to the axes of the plane on which the third view is located, intersecting these axes at e_1 and f_1.

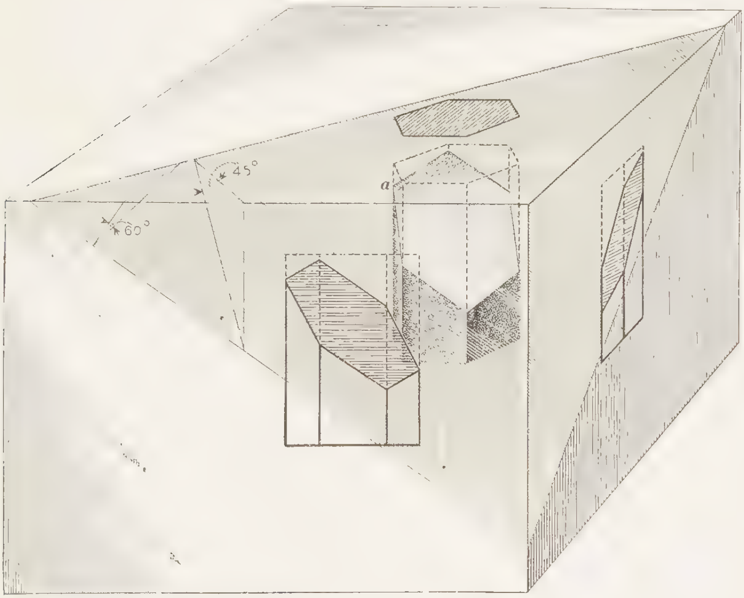
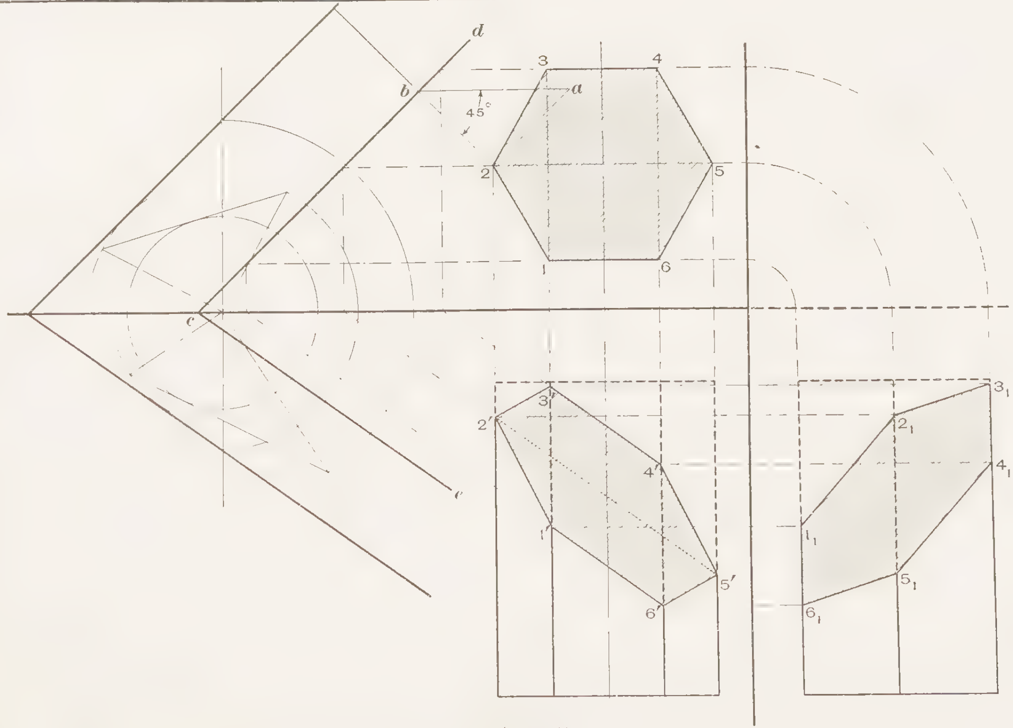


Fig. 14

On the revolved axis $j\,k$ lay off $j\,e_2 = j\,e_1$. Join e_2 and f_1 by a straight line cutting the projection $g_1\,h_1$ at i_1 Project the point i_1 on to $g\,h$ and $g'\,h'$; the points i' and i'' are projections of the point where the line in space pierces the plane whose traces are $a\,b$ and $a\,c$, on the given projections $g\,h$ and $g'\,h'$.

12. Problem 7. Sheet I.—A hexagonal prism measuring 2 inches across flats and having a height of $3\frac{1}{4}$ inches, with the ends at right angles to the center line, has its center line

Exercise II | Practical Projection, Part 5 | Sheet I



Problem 7

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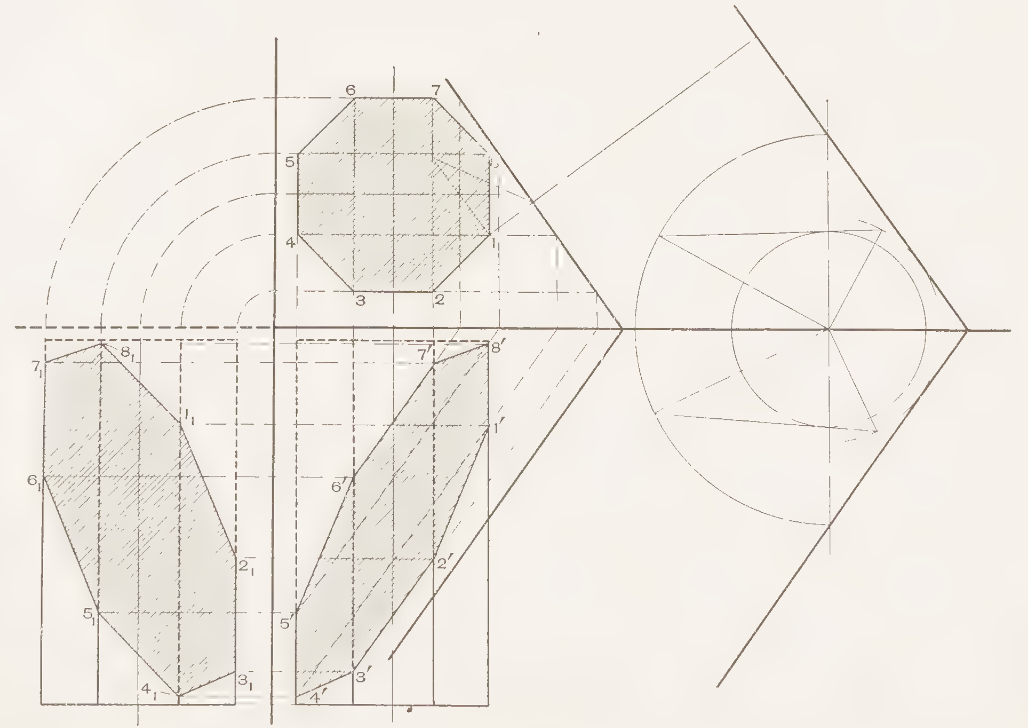
perpendicular to the horizontal plane and one of the flats parallel to the front plane. The center line is $1\frac{1}{2}$ inches from the front and side planes, and the upper end of the prism is $\frac{3}{4}$ inch from the horizontal plane. Through a point a, Fig. 14, of the vertical edge farthest from the side plane, which is at the right, and which point a is $1\frac{1}{8}$ inches below the horizontal plane, passes a cutting plane that makes an angle of 45° with the horizontal plane and of 60° with the front plane, the inclinations being in the directions shown in Fig. 14. Draw the horizontal, front, and side projections of the sections, the side plane being at the right of the front plane.

Solution.—Referring to the reduced copy of Sheet I, Exercise II, draw the three views of the prism as it appears before passing the cutting plane through it, locating the horizontal axis $3\frac{1}{4}$ inches from the upper border line and the vertical and side axes 3 inches from the right border line. Next, find the direction of the horizontal and front traces of the cutting plane, using the construction explained in Art. **5.** The center of the circle used in that construction may be located $2\frac{1}{2}$ inches from the left border line and have a diameter of 2 inches. It should be remembered that these dimensions are given only to insure that the traces in this particular case will come within the border lines. To find the correct location of the traces, at the corner *2* of the plan view construct the right-angled triangle *2 a b*, in which the side *2 a* is $1\frac{1}{8}$ inches long and the angle *2 b a* 45°, the side *2 b* being perpendicular to the horizontal trace previously found. Through the point b draw the horizontal trace $c\,d$ parallel to the other one; through its intersection c with the horizontal axis draw the front trace $c\,e$ parallel to the front trace previously found. This method of locating the traces was explained in Art. **7.** To find where the lines defining the vertical edges of the prism in the front view pierce the cutting plane, use the method given in Art. **10.** Having obtained the points of intersection *1'*, *2'*, etc. in the front view, draw the front section, joining *1'* and *2'*, *2'* and *3'*, etc. by straight



Problem 8

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lines. The side section is readily projected from the front section by projecting the points of intersection $1'$, $2'$, etc. to the corresponding lines of the side view, and then drawing the straight lines $1_1\,2_1$, $2_1\,3_1$, etc.

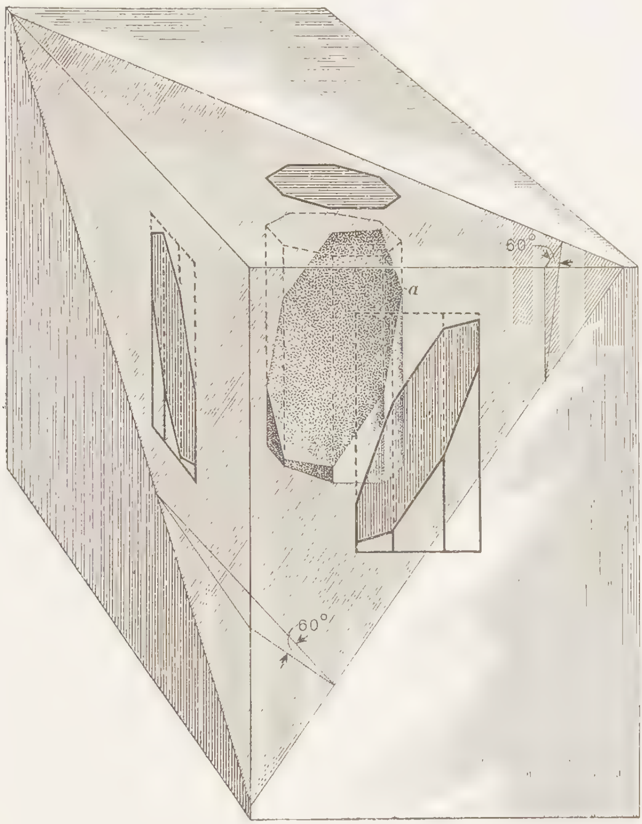


FIG. 15

13. PROBLEM 8. Sheet II.—A regular octagonal prism having a height of $3\frac{3}{4}$ inches and a width of 2 inches across the flat sides, with its ends at right angles to the center line, has the center line perpendicular to the horizontal plane and one of the sides parallel to the front plane, as shown in Fig. 15.

The center line of the prism is $1\frac{3}{8}$ inches from the front plane and $1\frac{1}{4}$ inches from the side plane, which is at the left of the front plane. The upper end of the prism is $\frac{1}{8}$ inch from the horizontal plane. Through the point a, Fig. 15, which is 1 inch from the horizontal plane, passes a cutting plane making angles of 60° with both the horizontal and front planes, in the direction clearly shown in the figure. Draw the horizontal, front, and side sections.

Locate the horizontal axis $3\frac{1}{2}$ inches from the upper border line and the vertical and side axes $3\frac{1}{8}$ inches from the left

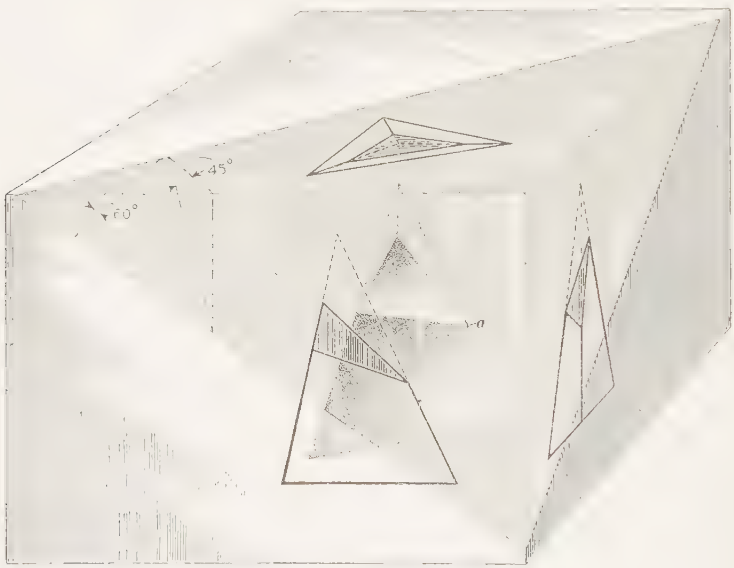
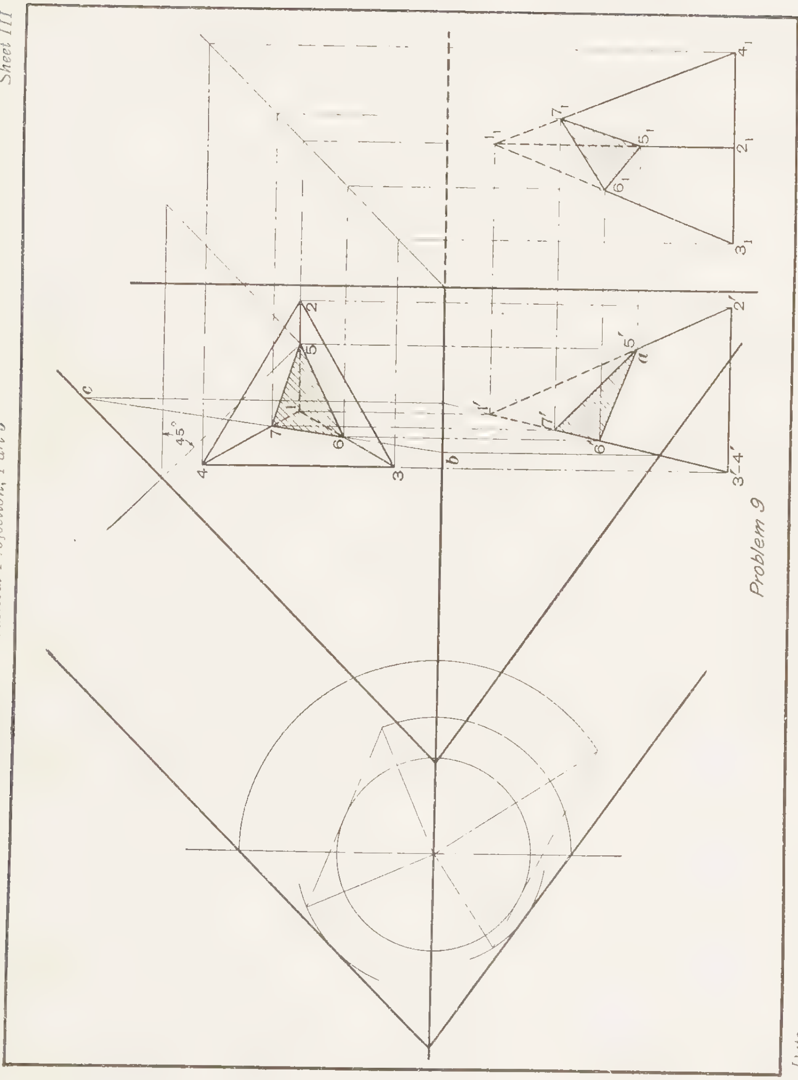


Fig. 16

border line. To insure that the traces of the plane parallel to the cutting plane will come within the border line, locate the center of the circle used in finding these traces $2\frac{1}{8}$ inches from the right border line and make the circle 2 inches in diameter.

14. Problem 9. Sheet III.—A pyramid whose base is a triangle with equal sides 2 inches long has a vertical height of $2\frac{1}{2}$ inches. The base is parallel to the horizontal plane

Exercise II — Practical Projection, Part 5 — Sheet III



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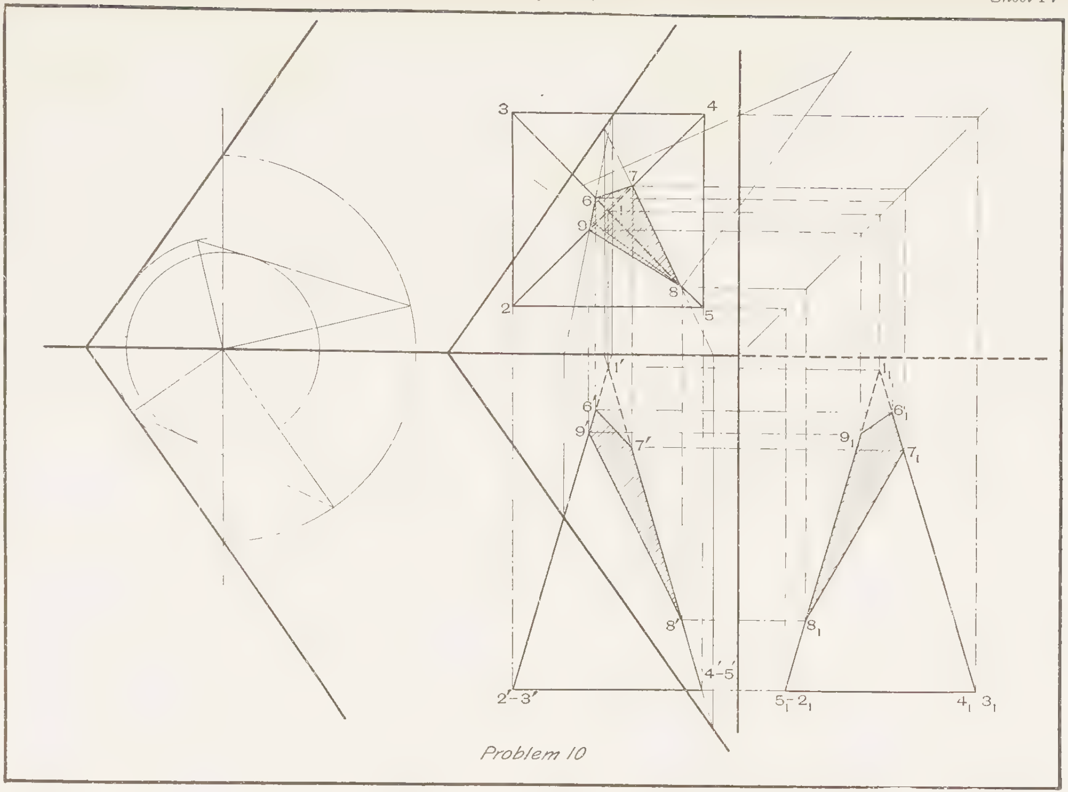
and 3 inches from it. One side of the base is parallel to the side plane and $1\frac{7}{8}$ inches from it. The corner of the base nearest the front plane is $\frac{1}{2}$ inch from it. Through the point *a*, Fig. 16, which is 2 inches from the horizontal plane, passes a cutting plane making an angle of 45° with the horizontal plane and of 60° with the front plane. Draw the horizontal, front, and side sections, the side plane being at the right of the front plane.

Solution.—Referring to the reduced copy of Sheet III, Exercise II, draw the horizontal axis $4\frac{3}{8}$ inches from the upper border line. Locate the vertical and side axes $2\frac{7}{8}$ inches from the right border line, and draw the three views of the pyramid according to the dimensions given. Find the traces of an auxiliary plane parallel to the cutting plane by the method explained in Art. **5.** The center of the circle used for this may be located $2\frac{1}{4}$ inches from the left border line, and the circle may have a diameter of about 2 inches. Next, lay off the point *a* on the front view 2 inches from the horizontal axis and project it to the horizontal view *1–2* of the edge whose front view is *1′–2′*. Now, by the method given in Art. **7,** locate the horizontal and front traces of the cutting plane. Using the method explained in Art. **8,** find the horizontal projections *6* and *7* of the points where the edges whose horizontal projections are marked *1–3* and *1–4* pierce the cutting plane. Project the points *6* and *7* to the front view; then project the points *5′*, *6′*, and *7′* to the side view. Complete the sections by joining the points of intersection just found by straight lines.

It will be noted that since the front projections of the edges whose horizontal projections are *1–3* and *1–4* coincide, the single line *b c* gives the projections *6* and *7* of the two points of intersection of the corresponding edges with the cutting plane.

15. Problem 10. Sheet IV.—A pyramid has a square base with sides 2 inches long, and a vertical height of $3\frac{3}{8}$ inches. The apex of the pyramid is directly over the center of the base; the base of the pyramid is parallel to the horizontal



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plane and $3\frac{1}{2}$ inches from it; two sides of the base are parallel to the front plane; the apex is $1\frac{1}{2}$ inches from the front plane and $1\frac{3}{8}$ inches from the side plane. Through the point a, Fig. 17, which is $2\frac{3}{4}$ inches below the horizontal plane, passes

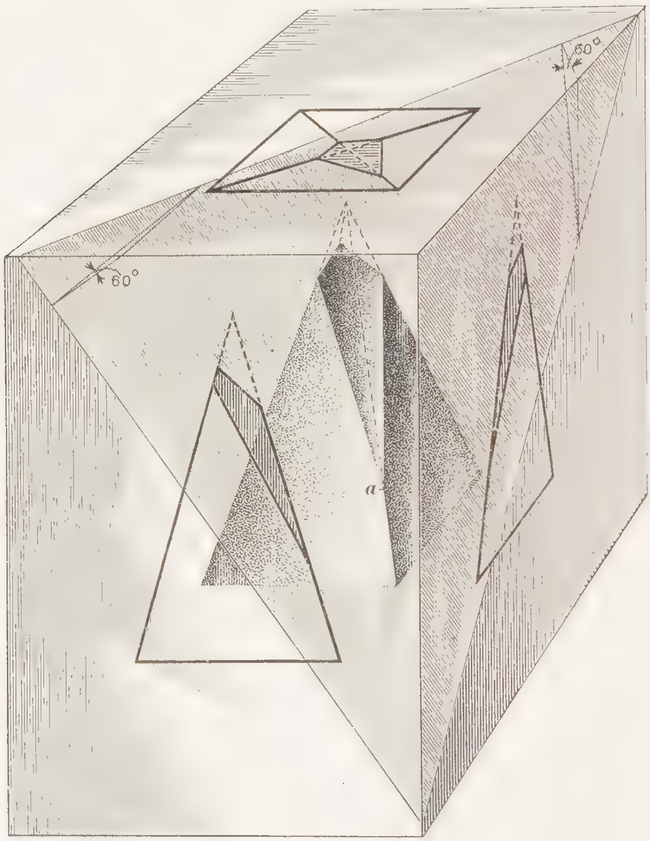


FIG. 17

a cutting plane making an angle of 60° with both the horizontal and front planes. Draw the three sections, the side plane being at the right of the front plane.

Locate the horizontal axis $3\frac{1}{2}$ inches from the upper border line and the vertical and side axes $3\frac{3}{8}$ inches from the right

border line. Locate the center of the circle used in finding the direction of the traces of the cutting plane $2\frac{1}{4}$ inches from the left border line and make the circle about 2 inches in diameter.

CONIC AND OTHER SECTIONS

EXERCISE III

16. The first three sheets of Exercise III contain problems relating to sections of the cone.

Any straight line drawn on the curved surface of a cone from the vertex to the base is called an *element* of that cone. The full view of the section of a right cone made by a cutting plane parallel to its base is a *circle;* if the cutting plane passes through the vertex and the base of the cone, the section is a *triangle;* if the cutting plane is at an oblique angle to the base, which angle is less than the angle made by the elements of the cone with the base, the section is an *ellipse* or part of an ellipse; if the cutting plane is parallel to any line drawn on the convex surface of the cone from the base to the vertex—that is, parallel to any element of the cone—the section is a *parabola;* if the cutting plane is at any angle (but not passing through the vertex of the cone) greater than the angle which the elements of the cone make with the base, the section is an *hyperbola.*

In a right cone, the base is a circle and the center line of the cone not only passes through the center of the base but is also perpendicular to the base. When the center line of a cone is not perpendicular to its base, the cone is said to be *scalene;* such cones are frequently met in boiler and sheet-metal work. Sections of scalene cones are projected by the same methods followed in the case of regular cones.

17. Problem 11. Sheet I.—A right cone whose base has a diameter of $2\frac{1}{4}$ inches has a vertical height of 3 inches. Its base is parallel to the horizontal plane and 1 inches from it; the center of the base is $1\frac{1}{2}$ inches from the front plane. A cutting plane perpendicular to the front plane and making

an angle of 45° with the horizontal plane, in the direction shown in Fig. 18, passes through the cone, cutting its center line $1\frac{13}{32}$ inches above the base. Draw the horizontal and front sections, and a full view of the section.

SOLUTION.—Referring to the reduced copy of Sheet I, Exercise III, draw the horizontal axis $3\frac{5}{16}$ inches from the upper border line. Draw the horizontal and front projections of the cone, locating the center line $1\frac{5}{8}$ inches from the left border line; draw the front trace *a b* of the cutting plane so

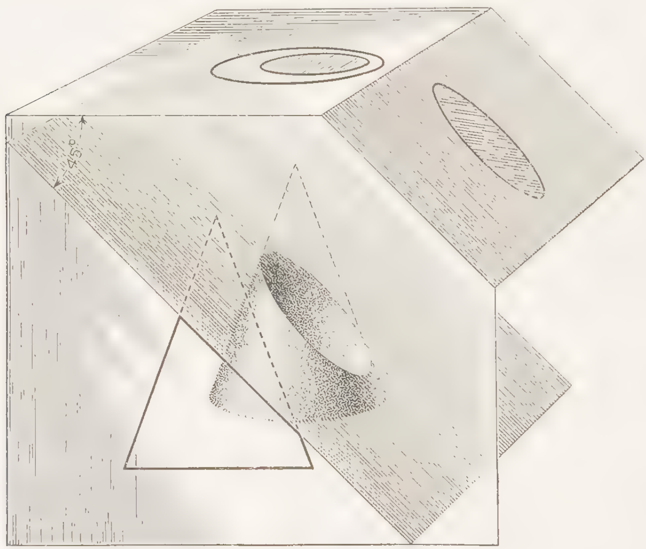


FIG. 18

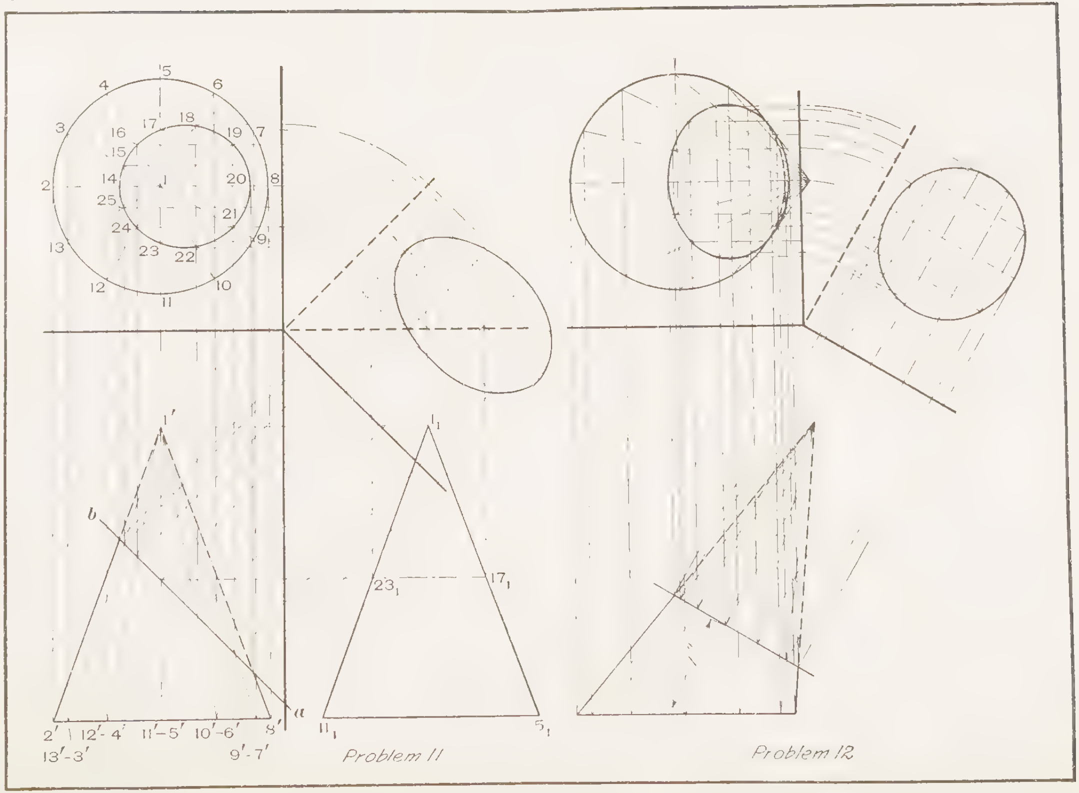
that it intersects the center line of the cone $1\frac{13}{32}$ inches from the base. In the horizontal view, divide the circle representing the base into any convenient number of equal parts, preferably a number divisible by 4, beginning where a line passing through the vertex and perpendicular to the horizontal axis cuts the circle representing the base, that is, at either the point *5* or the point *11*. Draw the horizontal projections *1 2*, *1–3*, *1–4*, etc. of the elements. Although it is permissible to draw the elements at random and a mathe-

matically correct result is obtained by doing so, there will be a great reduction in the number of lines needed by locating them in the manner just described. Project the points of division *2*, *3*, *4*, etc. to the front view of the base and draw the front projections *1′–2′*, *1′–3′*, *1′–4′*, etc. of the elements. From the points of intersection of the front projections of the elements with the front trace *a b*, draw projection lines to the corresponding horizontal projections of the elements. Since the horizontal and front projections of the elements, *1–5*, *1–11*, *1′–5′*, and *1′–11′*, are in the same straight line, the projections of intersection of the cutting plane with these projections of the elements cannot be obtained from the horizontal and front views, and a side view must be drawn. The vertical and side axes may be located $2\frac{7}{8}$ inches from the left border line. From the front view project the intersection of the front trace *a b* with the front projections *1′–5′* and *1′–11′*, which two projections coincide, to the side view, thus obtaining the intersections 17_1 and 23_1, which, in turn are projected to the horizontal view. Through the points *14*, *15*, *16*, etc. draw the elliptical outline of the section, omitting sectioning.

For obtaining the full view, an auxiliary plane may be located in any convenient position, and it may be turned on either trace, say as shown. Since the drawing of full views has been previously explained at great length, no directions for doing so will be given here.

Problem 12.—A scalene cone has a circular base $2\frac{5}{16}$ inches in diameter, and a vertical height of 3 inches. Its vertex is at a distance of $1\frac{3}{8}$ inches from a line passing through the center of the base and perpendicular to it. The base of the cone is parallel to the horizontal plane and 4 inches from it; a line joining the vertex and the center of the base is parallel to the front plane and $1\frac{1}{2}$ inches from it. A cutting plane perpendicular to the front plane and making an angle of 30° with the horizontal plane, in the direction shown in Fig. 19, passes through the cone, cutting the line joining the center of the base and the vertex at a point 1 inch from

Exercise III — Practical Projection, Part 5 — Sheet I



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the center of the base. Draw the horizontal and front sections, and a full view of the section, turning the auxiliary plane on its front trace. Omit sectioning the sections.

Locate the horizontal axis $3\frac{5}{16}$ inches from the upper border line; locate the center of the base 4 inches from the right border line; draw the horizontal trace of the auxiliary plane $2\frac{11}{16}$ inches from the right border line.

18. Problem 13. Sheet II.—A right cone whose base has a diameter of $2\frac{7}{32}$ inches and whose vertical height is

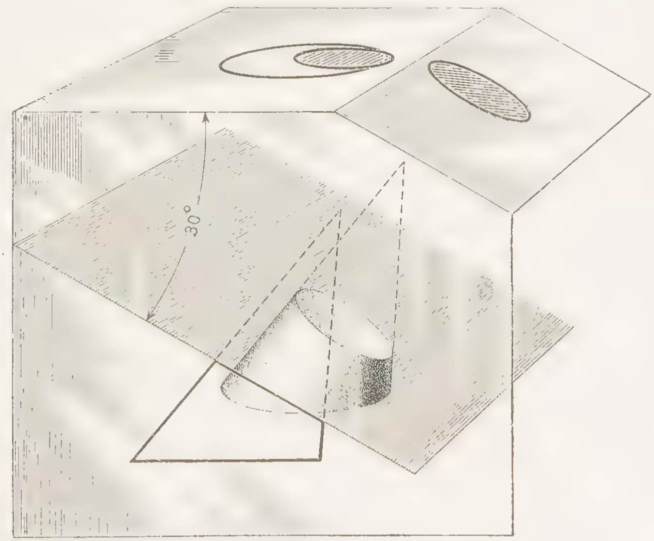
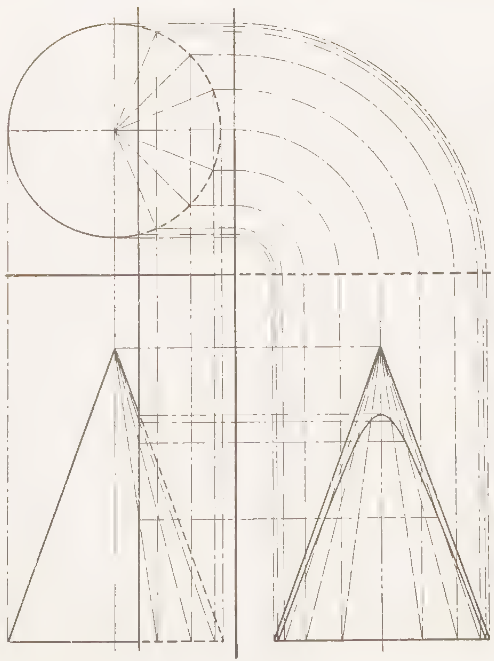


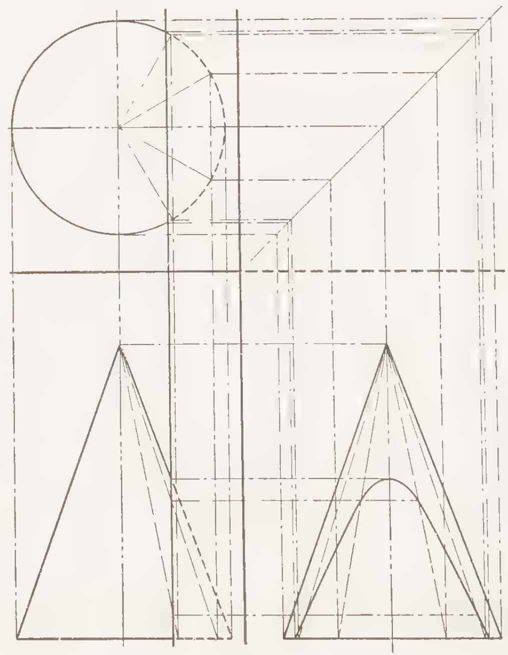
Fig. 19

3 inches has its base parallel to the horizontal plane and $3\frac{3}{4}$ inches from that plane. The center line of the cone is $1\frac{1}{2}$ inches from the front plane and $1\frac{1}{4}$ inches from the side plane. A cutting plane parallel to the side plane passes through the cone, as shown in Fig. 20, at a distance of $\frac{1}{4}$ inch from the center line of the cone. Draw the horizontal, front, and side views of the cone, showing the sections, the side plane being at the right of the front plane. Omit sectioning the full view of the section.

Exercise III | Practical Projection, Part 5 | Sheet II



Problem 13



Problem 14

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Locate the horizontal axis $3\frac{3}{8}$ inches from the upper border line and the vertical and side axes $2\frac{11}{16}$ inches from the left border line.

PROBLEM 14.—Draw the horizontal, front, and side views, and the sections of the same cone given in Problem 13, and which occupies the same position in reference to the principal planes, the cutting plane being parallel to the side plane and $\frac{1}{2}$ inch from the center line of the cone. The side plane is at the right of the front plane. Omit sectioning the full view of the section.

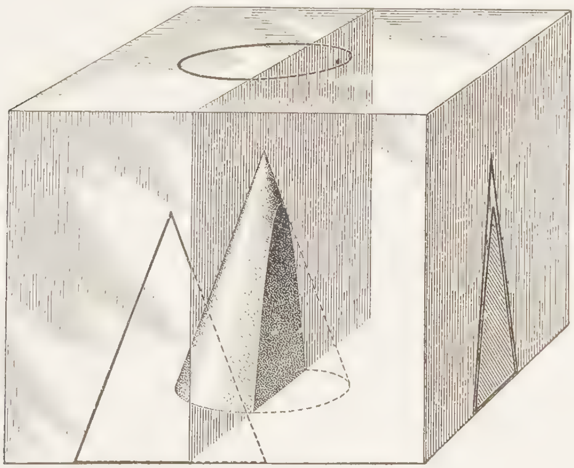
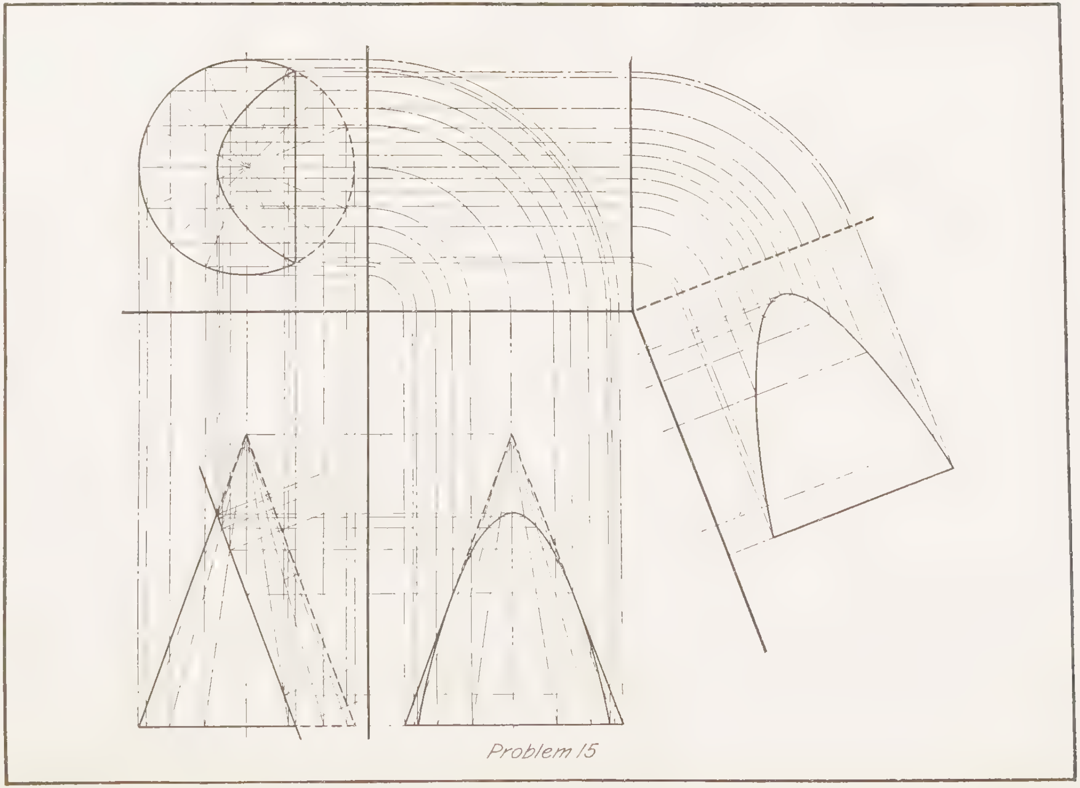


FIG. 20

Locate the horizontal axis $3\frac{3}{8}$ inches from the upper border line and the vertical and side axes $2\frac{15}{16}$ inches from the right border line.

19. PROBLEM 15. Sheet III.—A right cone whose base has a diameter of $2\frac{1}{4}$ inches has a vertical height of 3 inches. The base is parallel to the horizontal plane and at a distance of $4\frac{1}{4}$ inches from it. The center line of the cone is $1\frac{1}{2}$ inches from the front plane and $1\frac{1}{4}$ inches from the side plane. A cutting plane, parallel to a plane tangent to the convex surface of the cone and perpendicular to the front plane,



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passes through the cone, its direction being shown in Fig. 21. As an inspection of this figure will show, the front trace of the cutting plane is parallel to the line $a\,b$ of the front view. The cutting plane intersects the center line of the cone $1\frac{11}{32}$ inches from the base. Draw the horizontal, front, and side views, and the sections of the cone; also a full view of the section. The side plane is at the right of the front plane. Omit sectioning the sections.

Locate the horizontal axis $3\frac{3}{16}$ inches from the upper border line; locate the vertical and side axes $3\frac{3}{4}$ inches from the left

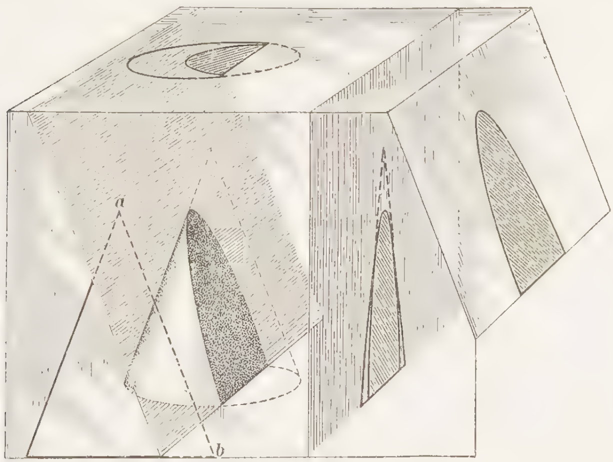


Fig. 21

border line. The horizontal trace of the auxiliary plane used for the full view may be located $4\frac{1}{2}$ inches from the right border line.

20. The same principle that is employed for finding sections of cones, that is, finding the intersections with the cutting plane of elements drawn on the curved surface, is made use of to find sections of other solids having regularly or irregularly curved surfaces intersected by a cutting plane. Such a solid, which is of frequent occurrence in sheet-metal work, is the *transition piece* shown in Fig. 22 (a), which, when of the form shown, is used to connect a rectangular opening

to a round one smaller in size. This particular form of transition piece has four triangular plane surfaces, as *a b c* and *c d e*, joined by four conical surfaces, as *a c d* for instance.

When drawing elements on the surface of solids in which plane surfaces are joined by curved ones, the lines of junction

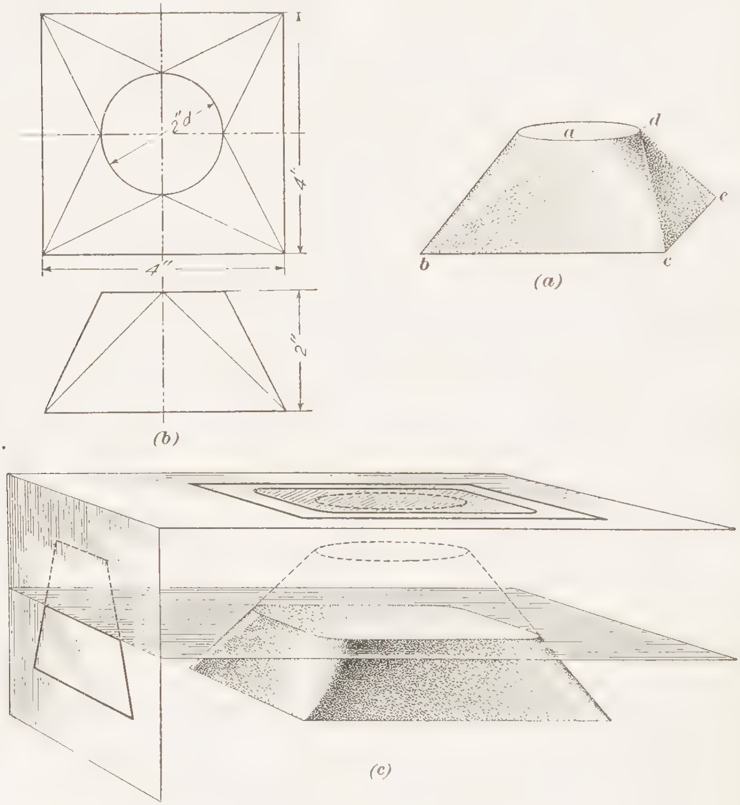
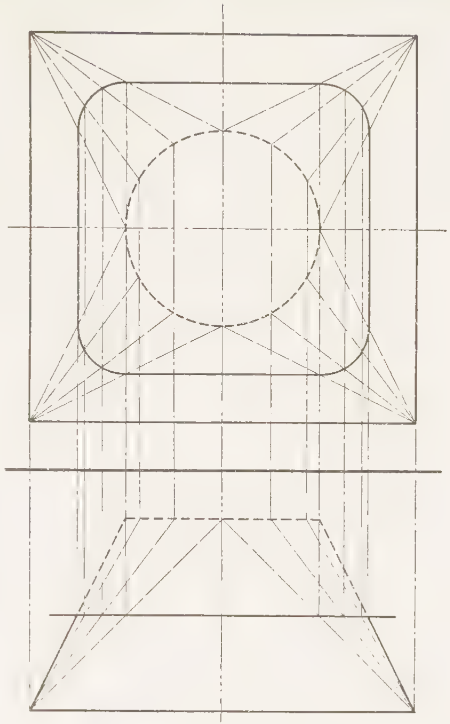
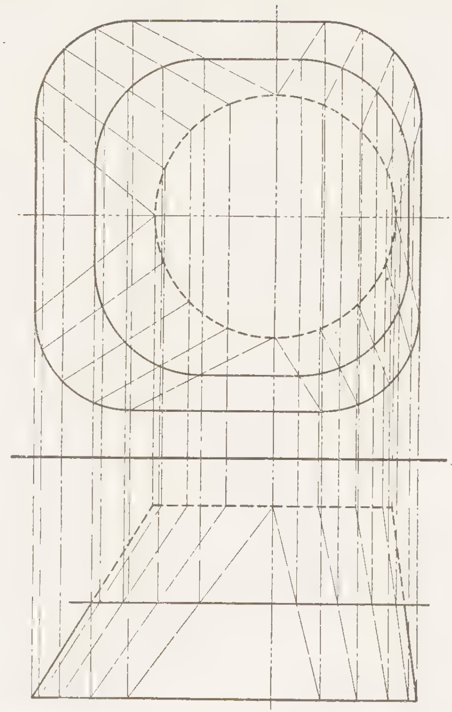


FIG. 22

of such surfaces, as the lines *a b*, *a c*, *c d*, and *d e* in Fig. 22 (*a*) for instance, are taken as some of the elements. The curved surfaces between the lines of junction are then subdivided by such other number of elements as is dictated by judgment. No elements need to be drawn on the plane surfaces intersected by the cutting plane.



Problem 16



Problem 17

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When drawing elements on curved surfaces, care must be taken to locate them in such a position that each element is a straight line.

21. Problem 16. Sheet IV.—A transition piece having the dimensions given in Fig. 22 (*b*), in which figure the fine solid lines denote the junction of the curved and plane surfaces, has its base parallel to the horizontal plane and two edges parallel to the front plane, as indicated in Fig. 22 (*c*). The base is $2\frac{1}{2}$ inches from the horizontal plane, and the center line is $2\frac{1}{2}$ inches from the front plane. A cutting plane parallel to the horizontal plane passes through the object 1 inch above its base. Draw the horizontal section, omitting section lining.

Locate the horizontal axis 5 inches from the upper border line and the center line 3 inches from the left border line.

Problem 17. An eccentric transition piece having a square base with rounded corners and a circular top, has the dimensions given in Fig. 23. The fine solid lines in that figure denote the junction of the plane and curved surfaces. The base is parallel to the horizontal plane and $2\frac{1}{2}$ inches from it. The center line *a b* is $2\frac{1}{2}$ inches from the front plane. A cutting plane parallel to the horizontal plane passes through the object 1 inch above its base. Draw the horizontal section, omitting section lining.

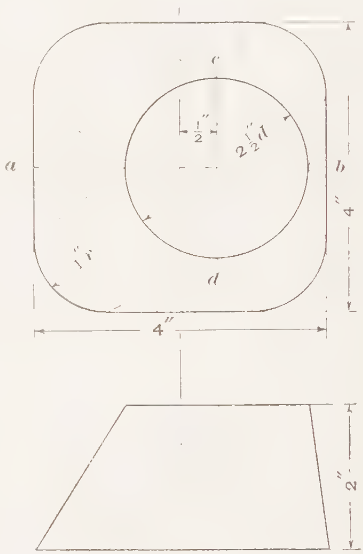


Fig. 23

Locate the horizontal axis 5 inches from the upper border line and the center line *c d* $2\frac{1}{2}$ inches from the right border line.

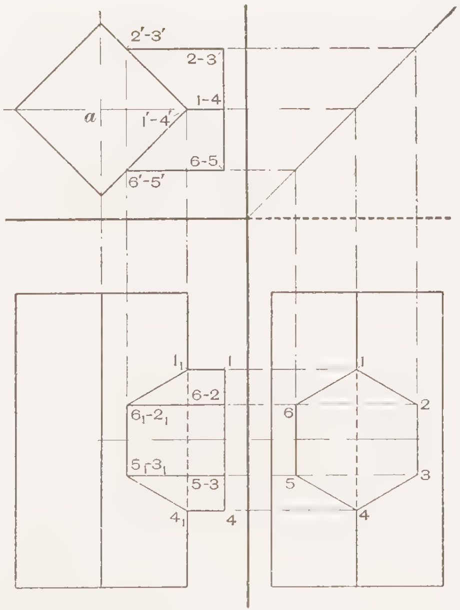
PRACTICAL PROJECTION
(PART 6)

PROJECTION OF INTERSECTIONS

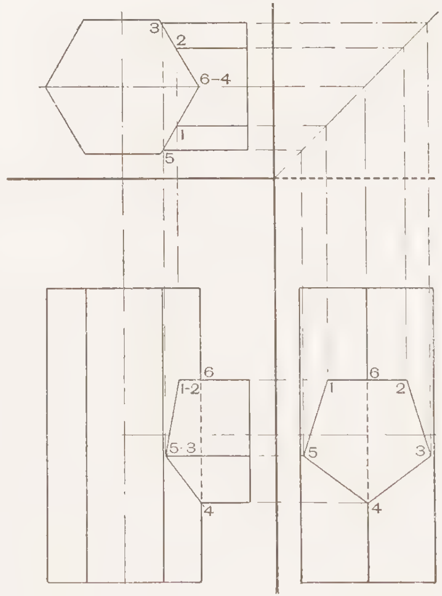
INTERSECTION OF PLANE SURFACES

EXERCISE I

1. To represent properly the intersections of the surfaces of solids—or to "draw the miter line," as it is commonly called—is the last process of projection used before the patterns for any sheet-metal work may be developed, or the projection drawings of intersecting solids may be completed. It has already been remarked that plane surfaces intersect in a line; the representation of the intersection of plane surfaces is therefore a very simple process, the draftsman merely having to define each surface by the application of the regular projection methods already explained. The intersection of curved surfaces, or of plane and curved surfaces, is apparently more complicated, but only because it is necessary to locate more points than are required for the intersection of plane surfaces. The location of points for the representation of the intersection of curved surfaces is done in a manner somewhat similar to that already shown in connection with the projection of plane surfaces having curved outlines. There is, however, this important difference to be observed: in the case of the plane surfaces with curved outlines, their projection is accomplished by means of *points* located on



Problem 1



Problem 2.

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their outlines; and in the case of the intersection of plane and curved surfaces, or curved surfaces, it is necessary to locate *lines* in such positions on each surface that they will lie in the same plane, although drawn on different surfaces. This is done in practice by passing cutting planes in any convenient direction through the two intersecting solids, and finding a partial or complete outline of the section corresponding to each cutting plane. Then, the points where the outlines of the section of each of the intersecting solids intersect, determined on each cutting plane, are points on the miter line of the two intersecting curved surfaces.

No drawing of an object in which intersected solids are represented is complete unless the line of intersection is accurately projected. This is a very important part of the drawing, since the correctness of the pattern in work of this class depends entirely on the accuracy with which the line of intersection is drawn.

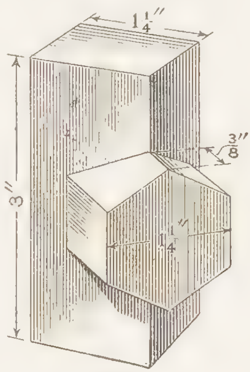


FIG. 1

2. PROBLEM 1. Sheet I.—A square and a hexagonal prism, having the dimensions given in Fig. 1, intersect as shown. The center lines of the two prisms intersect midway between the ends of the square prism, and are at right angles. Draw a top, a front, and a side view, the side plane being at the right of the front plane. The center line of the square prism is parallel to the front plane; the plane end surface of the hexagonal prism is parallel to the side plane. The center lines intersect midway between the ends of the square prism. The two ends of the square prism and the free end of the hexagonal prism are at right angles to their axes.

SOLUTION.—Referring to the reduced copy of Sheet I, Exercise I, in any convenient location, say $3\frac{3}{16}$ inches from the left border line and $3\frac{1}{8}$ inches from the upper border line, draw the vertical and side axes and the horizontal axis.

In any convenient location in reference to the front and side planes, say $1\frac{1}{8}$ inches from the horizontal axis and $1\frac{1}{2}$ inches from the side axis, locate the horizontal projection a of the center line of the square prism and draw the top view of that prism. Locate the side projection of the center line on the side plane and draw the side view of the square prism with its upper end at any convenient distance from the horizontal plane, say $\frac{3}{4}$ inch. Draw the side view of the hexagonal prism and from this project its top view. Then, the intersection of the horizontal projections 1–$1'$, 2–$2'$, etc. of the edges of the hexagonal prism with those two vertical sides of the square prism that are intersected, are the horizontal projections of corners of the miter line.

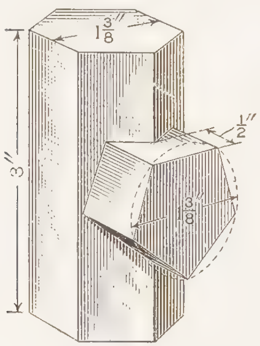
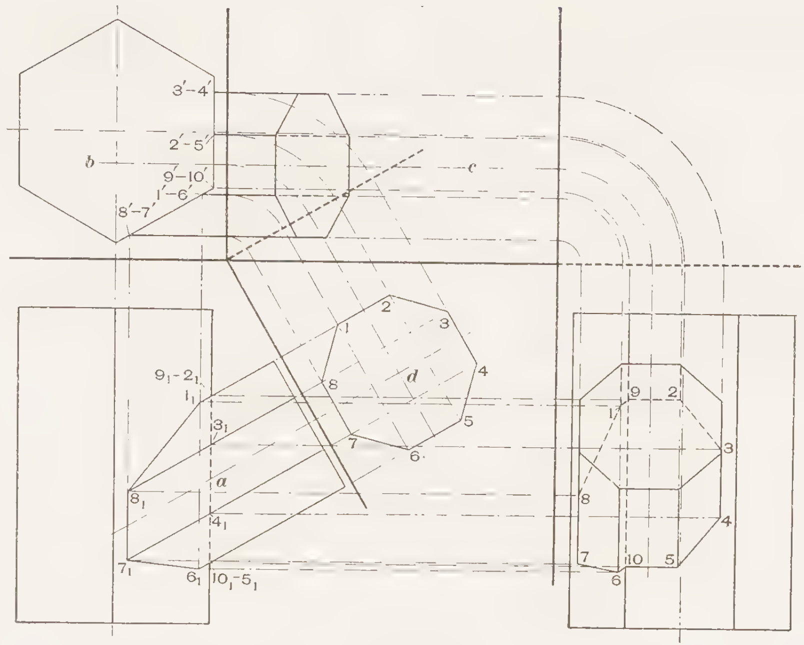


FIG. 2

Draw the front view of the square prism and from the side view project across the front projections of the edges of the hexagonal prism. From the top view project downwards the intersections $2'$, $3'$, $5'$, $6'$ on the front projections of the edges of the hexagonal prism, thus obtaining the corners 2_1, 3_1, 5_1, 6_1 of the miter line. The corners 1_1 and 4_1 of the miter line are given by the intersection of the front projections 1–1_1 and 4–4_1 with the front projection of the right-hand vertical edge of the square prism. Join the corners 1_1 and 6_1, 6_1 and 5_1, and 5_1 and 4_1 by straight lines, thus completing the drawing. The miter line in this case is formed by straight lines, because it represents the intersections of several plane surfaces, the intersection of two plane surfaces always being a straight line; consequently, the projections of the intersection are straight lines or a point, depending on their position in reference to the planes of projection.

PROBLEM 2.—A hexagonal prism and a pentagonal prism, having the dimensions given in Fig. 2, intersect in the manner shown. The center lines of the two prisms intersect



Problem 3

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midway between the ends of the hexagonal prism and are at right angles. Draw a top, a front, and a side view, the side plane being at the right of the front plane. The end surface of the pentagonal prism is parallel to the side plane; the center line of the hexagonal prism is perpendicular to the horizontal plane. The two ends of the hexagonal prism and the free end of the pentagonal prism are at right angles to their axes.

Locate the horizontal axis $2\frac{3}{4}$ inches from the upper border line and the vertical and side axes $2\frac{7}{16}$ inches from the right border line. Locate the horizontal projection of the center line of the hexagonal prism $\frac{15}{16}$ inch from the front plane and $1\frac{9}{16}$ inches from the side plane; draw the front view of the hexagonal prism so that its upper end is $1\frac{1}{8}$ inches from the horizontal plane.

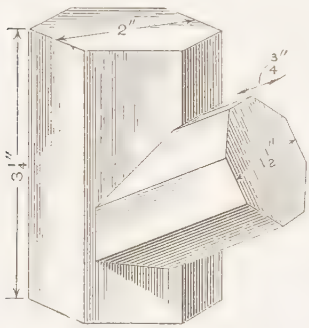


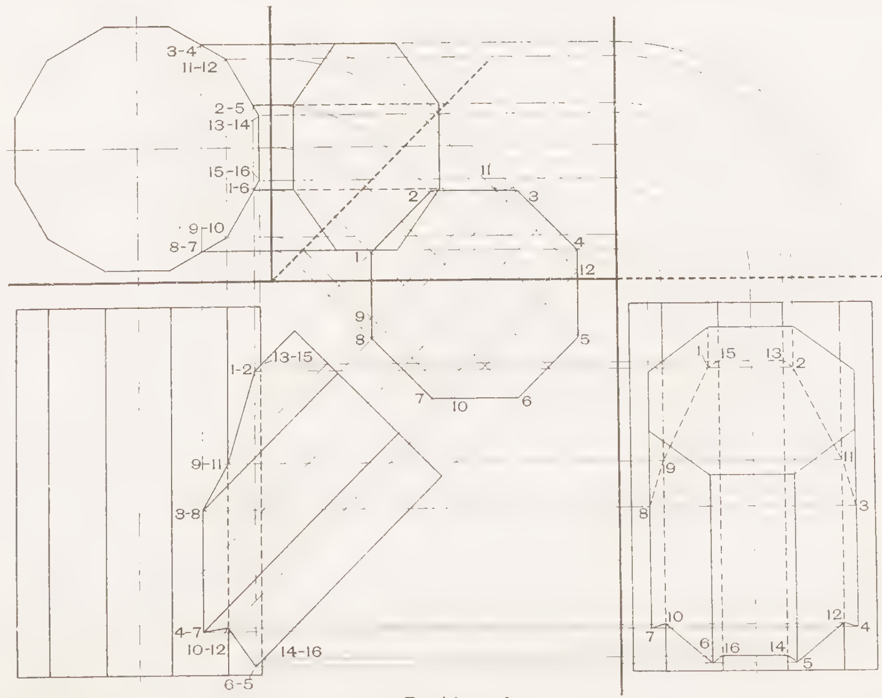
FIG. 3

3. The method of finding the miter line of intersecting solids bounded by plane surfaces, when the center lines of the solids are not at right angles and do not intersect, is no different from that employed for solving Problems 1 and 2, except that usually with at least one of the intersecting solids the exact location of the projections of its edges must be determined from a full view drawn on an auxiliary plane turned on one of its traces.

4. PROBLEM 3. Sheet II.—A hexagonal prism and an octagonal prism having the dimensions given in Fig. 3 intersect in such a manner that the center line of the octagonal prism makes an angle of 30° with the base of the hexagonal prism, the two end surfaces of this prism being at right angles to its body. The free end of the octagonal prism is at right angles to its axis. The center line of the octagonal prism is $\frac{5}{16}$ inch to one side of the center line of the hexagonal prism, and intersects one side of the hexagonal prism $1\frac{1}{2}$ inches from its base. Draw a top, a front, and a side view, the side

plane being at the right of the front plane, locating the prisms in such a manner that the center line of the hexagonal prism is perpendicular to the horizontal plane, and that the center line of the octagonal prism is in a plane parallel to the front plane.

Solution.—Referring to the reduced copy of Sheet II, Exercise I, in any convenient location, say $3\frac{5}{16}$ inches from the upper border line, draw the horizontal axis, and about $3\frac{15}{16}$ inches from the right border line draw the vertical and side axes. About $4\frac{9}{16}$ inches from the side axis and $1\frac{5}{16}$ inches from the horizontal axis, locate the horizontal projection of the center line of the hexagonal prism; draw the horizontal and front projections of the hexagonal prism, locating the front projection of its upper end $\frac{1}{2}$ inch from the horizontal axis. On the front projection lay off the point a $1\frac{1}{2}$ inches from the base of the prism and draw the front projection of the center line of the octagonal prism. At any convenient distance from the center of the horizontal view, say $1\frac{1}{8}$ inches, draw the horizontal trace of an auxiliary plane on which is to be located the full view of the end of the octagonal prism. Draw the front trace of the auxiliary plane at right angles to the front projection of the center line of the octagonal prism; also, draw the revolved horizontal trace at right angles to the front trace. Draw the horizontal projection $b\ c$ of the center line of the octagonal prism $\frac{5}{16}$ inch from the center of the top view of the hexagonal prism. Transfer the intersection of the line $b\ c$ with the horizontal trace to the revolved horizontal trace and draw a straight line parallel to the front trace to intersect at d the front projection of the center line of the octagonal prism; the point d is the center of the full view of the end of that prism, and has been located in correct relation to the horizontal and front projections of its center line. Draw the full view and from it project across the front trace lines containing the front projections of the edges of the octagonal prism. By projecting first to the revolved horizontal trace, and by transfer to the horizontal trace, find the correct position of the horizontal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Problem 4

projections of the edges of the prism. Draw the front projection of the end of the octagonal prism and from this projection determine the horizontal projection of the end surface. Next, by projecting downwards the points *1′*, *2′*, *3′*, etc. find the corners 1_1, 2_1, 3_1, etc. of the miter line and draw the miter line.

The side view of the two intersecting solids, including the side view of the miter line, is readily found by projecting corresponding points from the horizontal and front views.

5. Problem 4. Sheet III.—A regular twelve-sided prism with ends at right angles to its center line is intersected by a regular octagonal prism in such a manner that the two center lines intersect and that the center line of the octagonal prism makes an angle of 45° with the base of the twelve-sided prism. The center line of the octagonal prism intersects the middle of one of the sides of the other prism at a point $1\frac{21}{32}$ inches above its base. The dimensions of the two prisms are given in Fig. 4.

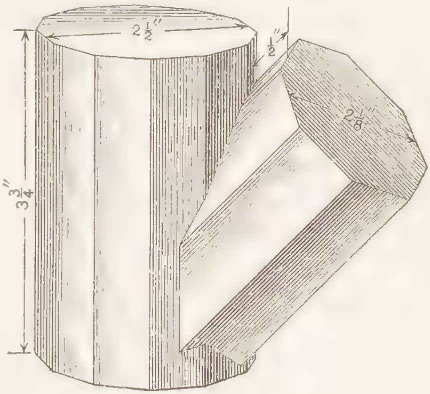


Fig. 4

The center line of the twelve-sided prism is perpendicular to the horizontal plane and $1\frac{3}{8}$ inches from the front plane; its distance from the side plane is $4\frac{15}{16}$ inches. The center line of the octagonal prism is in a plane parallel to the front plane. The upper end of the twelve-sided prism is $\frac{1}{4}$ inch from the horizontal plane. Draw a top, a front, and a side view, the side plane being at the right of the front plane. The ends of the large prism and the free end of the small prism are at right angles to their axes. Locate the horizontal axis $3\frac{5}{16}$ inches from the upper border line and the vertical and side axes $3\frac{3}{4}$ inches from the right border line.

6. It often occurs that solids intersect in such a manner that projection drawings of them cannot be made without having some of the lines defining one of the solids, or perhaps some lines of all the solids, inclined to all the principal planes. A case illustrating this is shown in Fig. 5, where a rectangular horizontal beam *a* is intersected by another rectangular beam *b* which is inclined to the horizontal, the front, and the side planes. The particular case illustrated occurs quite frequently in the construction of roofs for buildings.

When the solid inclined to the three principal planes, as the beam *b* in Fig. 5, is to be projected so that it will conform to given dimensions, it will be noticed that, since some of the different lines are foreshortened, some dimensions cannot be laid off directly.

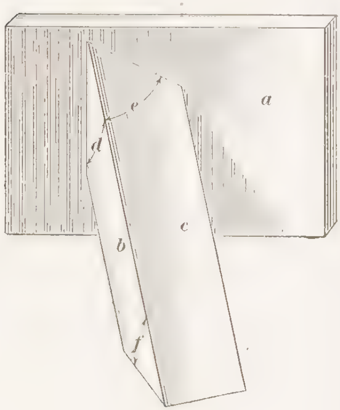


Fig. 5

7. The principle involved in locating a point in reference to a line inclined to the three principal planes is illustrated in Fig. 6, the case selected being the one most frequently occurring in practice, which is that the plane containing the point and the line in space is perpendicular to one of the principal planes.

Referring to Fig. 6 (*a*), let $a\,b$ be a line in space whose projections are the lines $a\,b'$ and $a_1\,b_1$, the horizontal plane for the sake of clearness being shown as passing through the upper end a of the line. Turn the plane that may be conceived to be bounded by $b\,b'$, $a\,b$, and $a\,b'$ around its trace $a\,b'$, which is also a projection of $a\,b$, until it is in the horizontal plane, as indicated by the triangle $a\,b'\,c'$. In this triangle the angle between $a\,b'$ and $b'\,c'$ is a right angle; the side $b'\,c'$ is equal to the length of the projection $b_1\,c$ of the projector $b\,b'$, and $a\,c'$ is the true length of the line $a\,b$. Now, on the plane containing $a\,b'\,c'$ lay off the point d at the given distance from the line $a\,c'$; this point d is the per-

pendicular distance $d\,d'$ from the line $a\,b'$. Now turn the plane of $a\,b'\,c'$, extended to take in the point d, around its trace $a\,b'$ until it is perpendicular to the horizontal plane, when $a\,c'$ will coincide with $a\,b$. The line $d'\,d$, which is per-

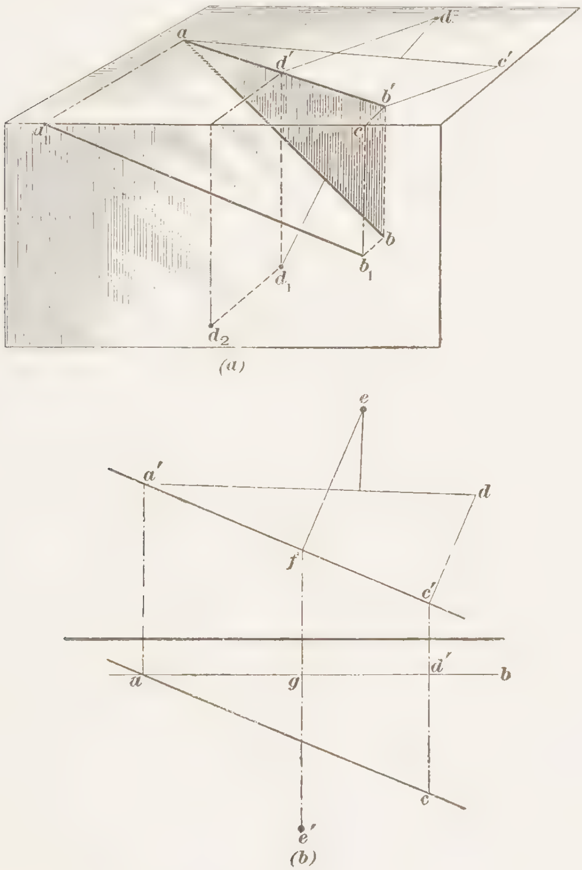


Fig. 6

pendicular to $a\,b'$, now occupies the position $d'\,d_1$ in space and is perpendicular to the horizontal plane, so that at d' is located the horizontal projection of the point d_1. The front projection will be at d_2, on the front trace of a plane perpendicular to the front and horizontal planes, and a distance

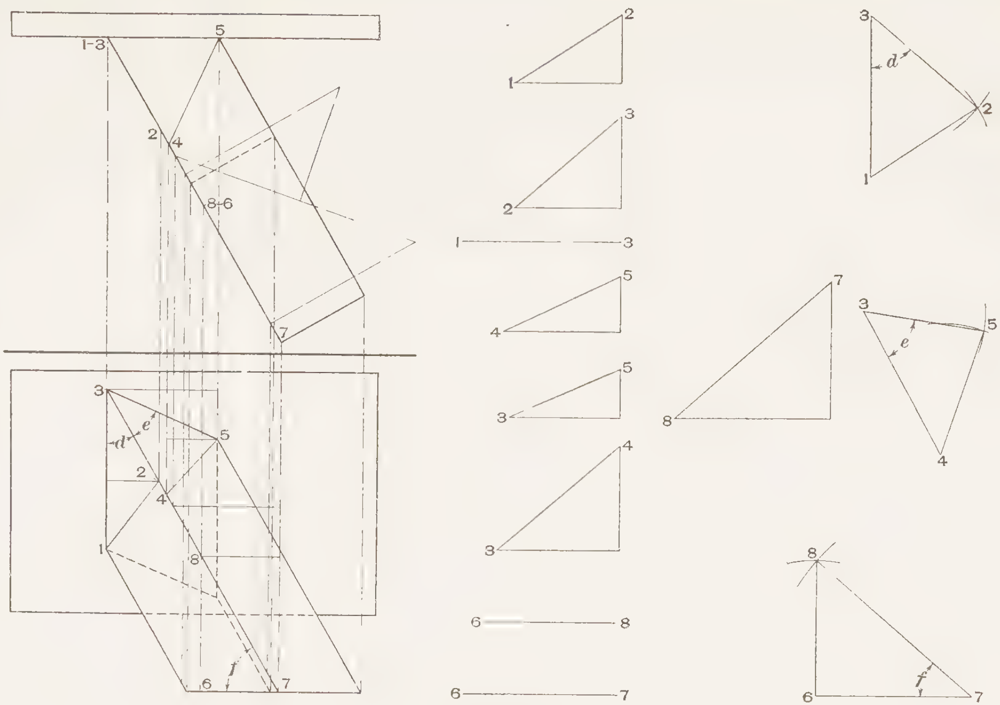
$d' d$ below the horizontal plane passed through the upper end of the line in space.

Hence the following construction: Referring to Fig. 6 (*b*), through some convenient point of one projection draw a line $a b$ parallel to the axis. Choose some convenient point on the same projection, as c, and project a and c to the second projection. At c' erect a perpendicular $c' d$, making its length equal to $c d'$. Draw $a' d$. Now lay off the point e in reference to the line $a' d$; draw the line $e f$ perpendicular to the projection $a' c'$. From f draw a projection line into the plane containing the projection $a c$; on this projection line, measuring from the line $a b$, lay off $g e'$ equal to $f e$. The point e' is then the one projection of the point e, and f is the second projection.

It will be plain that by locating two points in reference to the line shown in its true length, as $a c'$ in Fig. 6 (*a*), a straight line can be located at a given distance and angle in reference to it.

8. Problem 5. Sheet IV.—A rectangular and horizontal beam, as a in Fig. 5, is $3\frac{13}{16}$ inches long, $2\frac{1}{2}$ inches deep, and $\frac{1}{4}$ inch wide. It is intersected by another beam, as b in the same illustration, in such a manner that both the horizontal and front projections of the longitudinal edges of the beam make an angle of 60° with the horizontal axis, in the direction a study of the illustration will indicate. This second beam has a width of 1 inch and a depth of $1\frac{1}{4}$ inches. The surface marked b in the illustration is in a plane perpendicular to the horizontal plane and inclined to the front plane. The lower end of the beam b is cut off so that it is horizontal, its plane being $3\frac{5}{16}$ inches below the plane of the top of the beam a. The edge formed by the junction of the surfaces b and c intersects the beam a $\frac{3}{16}$ inch below the top and 1 inch to the right of the left end of the beam. Draw a horizontal and front projection, and determine the angles d, e, and f.

Solution.—Referring to the reduced copy of Sheet IV, Exercise I, draw the horizontal and front projections of the



Problem 5

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horizontal beam, locating the horizontal projection $\frac{1}{2}$ inch from the left and upper border lines and the upper edge of the front projection $4\frac{3}{16}$ inches from the upper border line. On the horizontal and front projections locate the point where the edge formed by the junction of the surfaces *b* and *c*, Fig. 5, meets the horizontal beam, and draw the two projections of the edge *c* at an angle of 60° to the horizontal axis. To find the length of the projections of the edge *c*, in the front view draw the front projection of the bottom end at the given distance from the upper surface of the horizontal beam, and project the intersection to the horizontal view. In the horizontal view lay off the width of the inclined beam, which is 1 inch; since this dimension is parallel to the horizontal plane, it shows in its true length and can be laid off directly. Complete the horizontal view. Since the vertical sides of the inclined beam are perpendicular to the horizontal plane, the projections of its top and bottom edges coincide. From the horizontal view project the front projection of the second upper edge and draw the line of intersection of the upper surface of the inclined beam with the horizontal beam. The front projection shows the depth of the beam; as this depth shows foreshortened, it must be laid off in the manner described in connection with Fig. 6. The front projection of the lower edges of the inclined beam having been drawn, complete the front view by drawing the complete miter line.

The angles *d*, *e*, and *f* may be found by drawing a full view of the respective surfaces; it is usually a good deal easier, however, to find these angles by triangulation. Thus, to find the angle *d*, draw in the front projection a straight line *1–2* in any convenient direction and project this line to the horizontal view, thus obtaining two projections of the triangle *1–2–3*. By the application of the principle of finding the true length of lines, find the true length of each side of the triangle, and with the true lengths of the sides construct the triangle *1–2–3*, as indicated in the upper right-hand corner of the reduced copy of the sheet containing the solution of the problem under discussion. Proceed in the same manner to find the angles *e* and *f*.

INTERSECTION OF PLANE AND CURVED SURFACES

EXERCISE II

9. The principle involved in finding the miter line of intersecting solids when one is bounded by plane surfaces and the other by curved surfaces has already been briefly stated in Art **1,** and will now be explained more in detail.

In Fig. 7 is shown a hexagonal prism intersected by a cylinder, the center line of the cylinder being inclined in

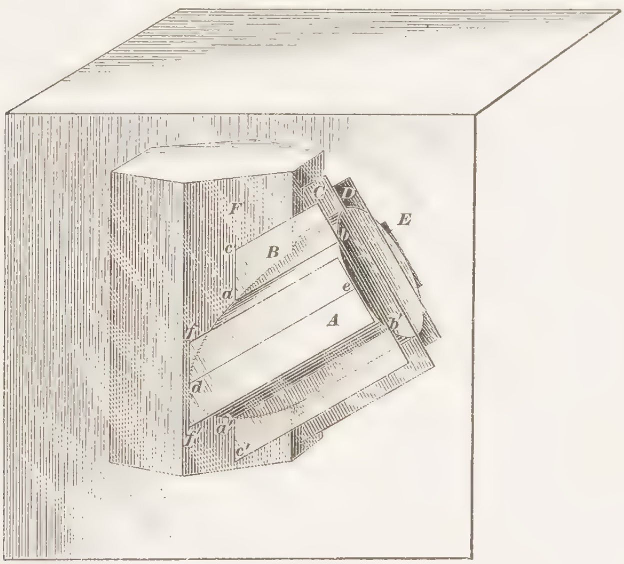


FIG. 7

respect to the center line of the prism. It should be distinctly understood that the principle involved in finding the miter line is the same whether the center lines of the two solids are at right angles or not, or whether the center lines intersect or do not intersect.

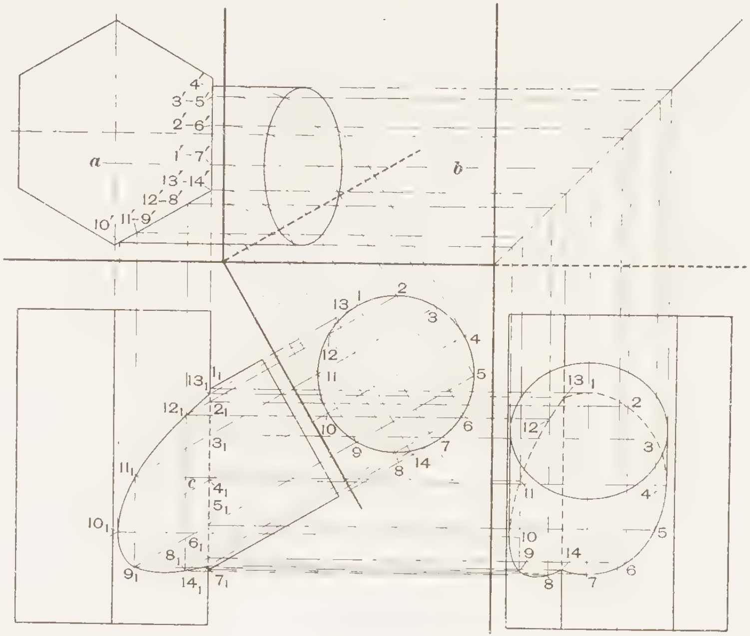
Through the cylinder, and tangent to the cylinder if deemed advisable, in any convenient direction pass a convenient

number of cutting planes, as A, B, C, D, and E. These cutting planes, when the shape of the solids permits this, should be taken in such a manner that the intersections of each cutting plane with the curved surface cut by it are two straight lines, both of which preferably should be parallel to one of the principal planes of projection. Thus, the cutting plane B (and all other cutting planes in the figure) has been taken parallel to the center line of the cylinder; and the prism being perpendicular to the horizontal plane, with the center line of the cylinder in a plane parallel to the front plane, the cutting plane B has also been taken parallel to the front plane. This insures that its intersections $a\,b$ and $a'\,b'$ with the cylinder are straight lines; it further insures that both intersections will be parallel to the front plane. Examination of the illustration shows that the cutting plane B intersects the surface F of the prism in the line $c\,c'$. Obviously, the points of intersection a and a' of the lines $a\,b$ and $a'\,b'$ with the line $c\,c'$ are two points on the miter line.

In the case of the plane A tangent to the cylinder, the line $d\,e$ is its line of tangency and the line $f\,f'$ its intersection with the surface F; the intersection d of the line $d\,e$ with the line $f\,f'$ is a point on the miter line.

When projection drawings of intersecting solids, the one bounded by plane surfaces and the other by curved surfaces, are to be made, it is usually advisable to so locate the views that the center line of the one solid will be perpendicular to one of the principal planes, and the center line of the other solid will be in a plane perpendicular to the same principal plane and parallel to another principal plane. When thus placed, the work of finding the miter line is greatly simplified; in fact, the solution of the problem becomes almost identical with that of Problems 1 to 4, differing only in that the miter line is a curve or composed of a series of curves.

10. Problem 6. Sheet I.—A regular hexagonal prism measuring 2 inches across the sides and having a height of $3\frac{1}{4}$ inches, with its ends at right angles to its center line, is intersected by a cylinder $1\frac{5}{8}$ inches in diameter whose center



Problem 6

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line is inclined 30° with the base of the prism, in the direction shown in Fig. 7. The center line of the cylinder intersects one of the sides of the prism $1\frac{1}{2}$ inches from its base, and is in a plane perpendicular to that flat side of the prism which it intersects. The vertical plane in which the center line of the cylinder is located is $\frac{5}{16}$ inch in front of the center line of the prism. From the point where the center line of the cylinder pierces the flat surface of the prism, to the end of the cylinder, is $1\frac{3}{32}$ inches, the end being at right angles to the center line.

With the center line of the prism perpendicular to the horizontal plane, and the center line of the cylinder in a plane parallel to the front plane, draw a top, a front, and a side view, the side plane being at the right of the front plane.

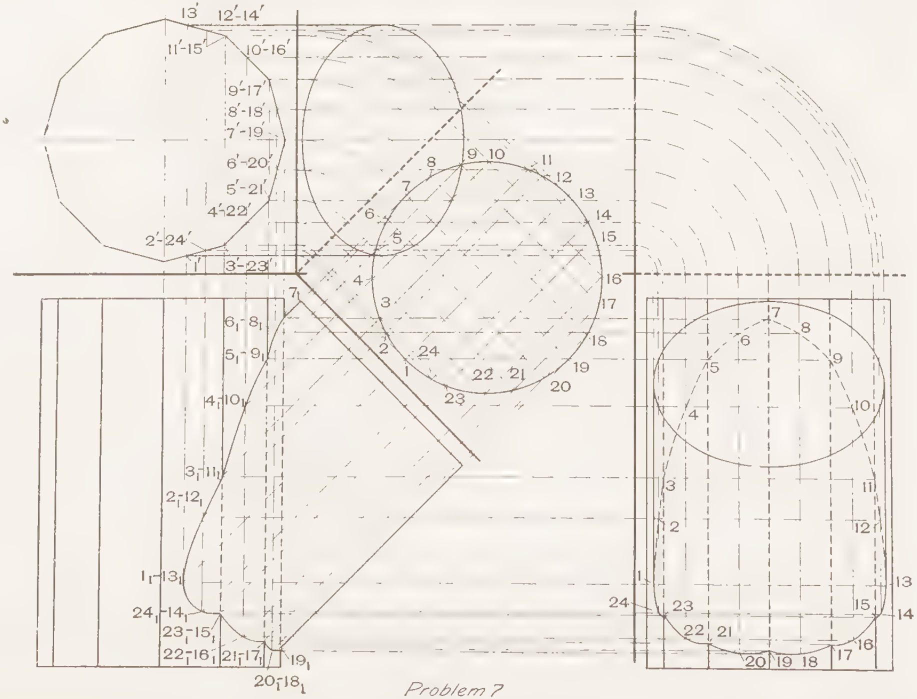
Solution.—Referring to the reduced copy of Sheet I, Exercise II, draw the horizontal axis in any convenient location, say $3\frac{5}{16}$ inches from the upper border line. Draw the vertical and side axes $4\frac{1}{4}$ inches from the right border line. In the horizontal plane locate the projection of the center line of the prism, which projection is a point, in any convenient place, say $3\frac{15}{16}$ inches from the side axis and $1\frac{5}{16}$ inches from the horizontal axis. Draw the top and front views of the prism, locating the top view at any convenient distance from the horizontal axis, say $\frac{1}{2}$ inch. On the horizontal plane now draw the horizontal projection $a\,b$ of the center line of the cylinder. In any convenient place, say $2\frac{13}{16}$ inches from the side axis, draw the horizontal trace of an auxiliary plane on which to draw the full view of the end of the cylinder. Draw the front trace at an angle of 120° with the horizontal axis, and draw the revolved horizontal trace. On the front view lay off the point c $1\frac{1}{2}$ inches above the base, and, at an angle of 30° with the base, or at right angles to the front trace, draw the front projection of the center line of the cylinder. By projecting from the top view find the correct location of the center of the full view of the end of the cylinder, and draw the circle representing it. Beginning at either one of the points marked *1*, *4*, *7*,

or *10*, divide the circle into a number of equal parts, preferably a number divisible by 4, say 12. Then, through the points *1* and *7*, *2* and *6*, *3* and *5*, etc., it is possible to pass cutting planes parallel to the front plane. By projecting across the front trace, the front projections of the intersections of these cutting planes with the cylinder are obtained. By projecting the points *1*, *2*, *3*, etc. of the full view to the revolved horizontal trace, and by transfer to the horizontal trace, the location of a point of each horizontal projection of the intersections of each cutting plane with the cylinder is given. Since the cutting planes were taken parallel to the front plane, the horizontal projections of their intersections with the cylinder are parallel to the horizontal axis, and should now be thus drawn. Next, the intersections $1'$, $2'$, etc. are projected downwards to meet the horizontal projections of the intersections of the cutting planes with the cylinder, thus obtaining the points 1_1, 2_1, 3_1, etc., which are points on the miter line.

It will be observed in the top view, and also by consulting Fig 7, that one edge of the prism is intersected by the cylinder. To obtain, on the miter line, its two intersections, project the horizontal projection of the edge, marked $13'$–$14'$, to the horizontal trace and transfer this projection to the revolved horizontal trace; then project to the full view, thus obtaining the points *13* and *14*. Project *13* and *14* across to the front view to meet the front view of the edge under discussion, thus obtaining the points 13_1 and 14_1 of the miter line. By means of an irregular curve, the curved part of the miter line that appears in the front view can now be traced.

By projecting from the full view and the front view the horizontal view of the end of the cylinder is easily determined. No special directions are needed for drawing the side view, this being simply a case of projecting one point after another from the horizontal and front views.

11. PROBLEM 7. Sheet II.—A regular twelve-sided prism, inscribed in a circle $2\frac{1}{2}$ inches in diameter, having a



Problem 7

height of $3\frac{3}{4}$ inches is intersected by a cylinder having a diameter of $2\frac{3}{8}$ inches. The two center lines intersect $\frac{5}{8}$ inch above the base of the prism; the center line of the cylinder passes through one edge of the prism and makes an angle of 45° with the base of the prism, in the direction shown in Fig. 8. Both the top and the base of the prism are at right angles to its center line; the free end of the cylinder is at right angles to its center line and at a distance of $1\frac{7}{16}$ inches from the point where the center line of the cylinder intersects one edge of the prism. Draw a top, a front, and a side view, the side plane being at the right of the front plane. Make the projections so that the two center lines will be in a plane parallel to the front plane and at a distance of $1\frac{3}{8}$ inches from it. The center line of the prism is perpendicular to the horizontal plane. Locate the top of the prism $\frac{1}{4}$ inch from the horizontal plane.

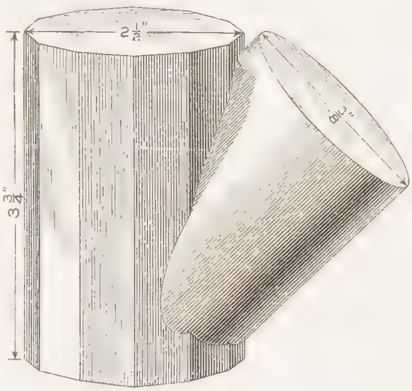


FIG. 8

Locate the horizontal axis $3\frac{5}{16}$ inches from the upper border line and the vertical and side axes $3\frac{3}{4}$ inches from the right border line. Locate the horizontal projection of the center line of the prism $4\frac{7}{8}$ inches from the side axis.

INTERSECTION OF CURVED SURFACES

EXERCISE III

12. The solution of the problem of finding the intersection of two cylinders does not differ in any particular from finding the intersection of a prism and cylinder, the principle illustrated by the aid of Fig. 7 being employed.

There is a special case of intersection of cylinders that is of very frequent occurrence in practice, in which the miter line rarely needs to be found point by point; this case is the intersection of cylinders of equal diameter and with intersecting center lines. With such cylinders the miter line is a straight line bisecting the angle between the cylinders, in any view in which the center lines of the cylinders are in a plane parallel to the plane of projection.

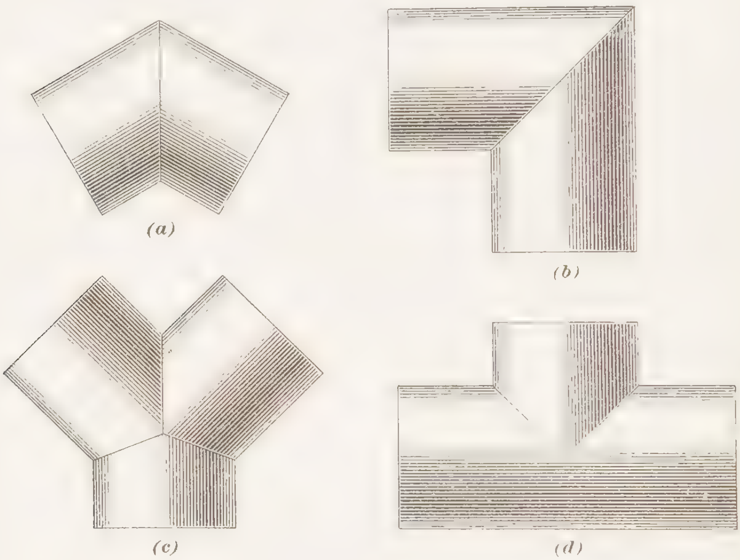
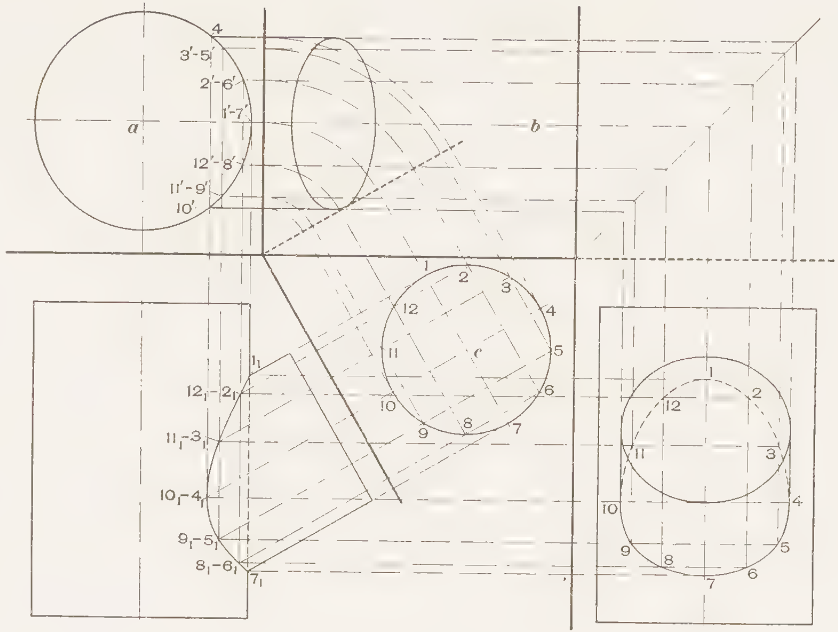


Fig. 9

Some examples of frequent occurrence in sheet-metal work are shown in Fig. 9, the ones in (*a*) and (*b*) being pipe elbows; the one in (*c*) is a **Y** fitting, and the one in (*d*) a **T**.

It may be remarked here that when similar moldings intersect, or miter, and like parts meet like parts, the miter line will be a straight line bisecting the angle between adjacent pieces of molding, in any view in which the true length of all members of such moldings will be shown.

13. Problem 8. Sheet I.—A cylinder $2\frac{1}{4}$ inches in diameter and $3\frac{1}{4}$ inches high is intersected by a cylinder



Problem 8

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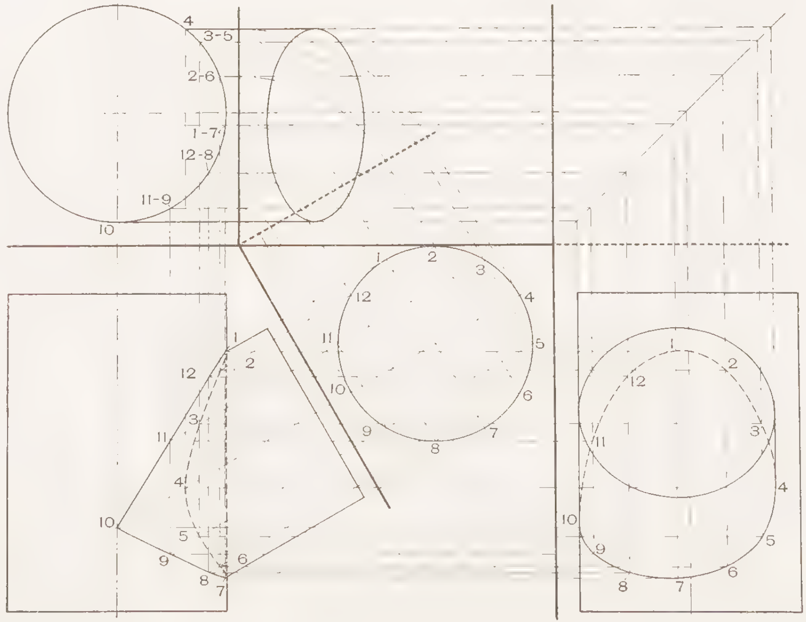
$1\frac{3}{4}$ inches in diameter; the center lines of the two cylinders intersect. The ends of the large cylinder are at right angles to its center line; the free end of the small cylinder is at right angles to its center line. The center line of the small cylinder makes an angle of 30° with the base of the large cylinder and passes through the curved surface of the large cylinder $1\frac{1}{2}$ inches above the base. The distance from the point where the center line of the small cylinder intersects the surface of the large cylinder to the free end of the small cylinder is 1 inch. Draw a front, a top, and a side view, the side plane being at the right of the front plane; draw these views with the center lines in a plane parallel to the front plane and the center line of the large cylinder perpendicular to the horizontal plane.

Solution.—Referring to the reduced copy of Sheet I, Exercise III, in any convenient position, say $3\frac{3}{8}$ inches from the upper border line, draw the horizontal axis, and about $3\frac{15}{16}$ inches from the right border line draw the vertical and side axes. In any convenient place on the horizontal plane, say $4\frac{1}{2}$ inches from the side axis and $1\frac{3}{8}$ inches from the horizontal axis, locate the horizontal projection a of the center line of the large cylinder and draw the top view of the large cylinder. Draw the front view of the large cylinder at any convenient distance from the horizontal axis, say $\frac{1}{2}$ inch. Through the point a and parallel to the horizontal axis draw the horizontal projection $a\,b$ of the center line of the small cylinder. At any convenient distance from the side axis, say $3\frac{1}{4}$ inches, draw the horizontal trace of an auxiliary plane on which is to be located the full end view of the small cylinder; at an angle of 60° to the horizontal axis draw the front trace of the auxiliary plane, and at right angles to the front trace draw the revolved horizontal trace. Now draw the front projection of the center line of the small cylinder so that it intersects the large cylinder $1\frac{1}{2}$ inches from its base, extending this projection well into the auxiliary plane. Transfer the intersection of the projection $a\,b$ with the horizontal trace to the revolved horizontal trace, and project to

the front projection of the center line of the small cylinder to get the intersection *c*; with *c* as a center, draw the full end view of the small cylinder. Beginning at either one of the points marked *1*, *4*, *7*, or *10*, divide the circumference of the full end view into any convenient number of equal parts, preferably a number divisible by 4, say 12. Then, through the points *1* and *7*, *2* and *6*, etc. pass cutting planes parallel to the front plane and draw both the front projections and horizontal projections of the intersections of these cutting planes with the small cylinder; the horizontal projections intersect the horizontal projection of the large cylinder at $1'$, $2'$, $3'$, etc. From $1'$, $2'$, $3'$, etc. draw projection lines into the front plane to cut the front projections of the intersections of the cutting planes with the small cylinder, thus establishing the points 1_1, 2_1, 3_1, etc. of the miter line. With an irregular curve trace the front projection of the miter line. Complete the front view of the small cylinder.

From the full end view and the front view draw the horizontal projection of the free end of the small cylinder; by projecting from the completed horizontal and front views, draw the required side view.

14. PROBLEM 9. Sheet II.—A cylinder $2\frac{1}{4}$ inches in diameter and $3\frac{1}{4}$ inches high is intersected by a cylinder 2 inches in diameter at an angle of 30° with the base of the large cylinder, whose two ends are at right angles to its center line. The center line of the small cylinder pierces the large cylinder $1\frac{1}{2}$ inches from the base. The center lines of the two cylinders do not intersect; they pass each other at a distance of $\frac{1}{8}$ inch. The free end of the small cylinder is at right angles to its center line and is $1\frac{1}{16}$ inches from the point where the center line pierces the surface of the large cylinder. Draw a front, a horizontal, and a side view, the side plane being at the right of the front plane. Draw the views so that the center line of the large cylinder is perpendicular to the horizontal plane and the center line of the small cylinder is in a plane parallel to the front plane, and nearer the front plane than the center line of the large cylinder. The small



Problem 9

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cylinder is at the right of the large cylinder, and inclines downwards toward the base of the large cylinder.

Locate the horizontal axis $3\frac{3}{8}$ inches from the upper border line and the vertical and side axes $3\frac{15}{16}$ inches from the right border line. Locate the center line of the large cylinder $4\frac{1}{2}$ inches from the side plane and $1\frac{3}{8}$ inches from the front plane. Locate the upper end of the large cylinder $\frac{1}{2}$ inch from the horizontal plane. Draw the horizontal trace of the auxiliary plane $3\frac{1}{4}$ inches from the side axis.

15. The solution of the problem of finding the miter line of intersecting cones, irrespective of whether their center lines intersect or not, does not differ essentially from the solution employed in finding the miter line of intersecting cylinders. As indicated in Fig. 10, a convenient number of cutting planes are passed through the two cones in any convenient direction. In the case illustrated, the cutting planes were taken parallel to the base of the large cone, in which case a full view of each section of the large cone, this being a right cone, is part of a circle. In the illustration, the cutting planes are indicated by their intersections *a*, *b*, *c*, and *d* with the large cone and *e*, *f*, *g*, *h* with the small cone. Full views of the intersections of the cutting planes with the small cone in this particular case are parts of ellipses. The points *i*, *j*, *k*, and *l*, which are junctions of the outlines of the corresponding sections of the large and small cones, are points on the miter line.

As previously stated, the cutting planes may be taken in any convenient direction, and they need not be parallel to one another. However, it is inadvisable to select cutting planes that are inclined to the three principal planes, as thereby the labor of finding the sections is increased; experienced draftsmen will choose cutting planes that are either parallel to one and perpendicular to two principal planes, or inclined to two and perpendicular to one of the principal planes. As in the case of intersecting cylinders, it is advisable to so place the cones within the planes that the center line of one cone is perpendicular to a principal plane.

It is well to bear in mind that the finding of points on the miter line of two intersecting cones, or, as a matter of fact, of any two intersecting solids, resolves itself into finding the outlines of a number of sections taken through the two solids. However, it is not necessary to determine complete sections; thus, in Fig. 10 it will be sufficient to determine the part $a\ i$ of the section of the large cone and the part $m\ i$ of the section of the small cone in order to find the point i of the miter line.

The outlines of the sections of intersecting cones may be parts of circles, ellipses, parabolas, hyperbolas, or straight lines, depending on the direction of the cutting planes.

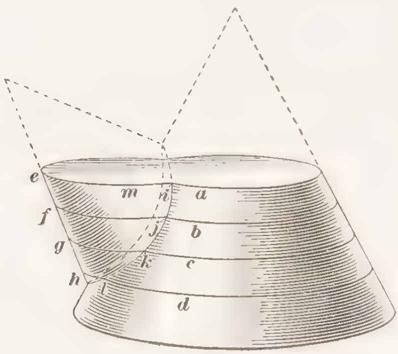


FIG. 10

16. In Fig 11 (a) are shown two orthographic projections of a cone, with some elements drawn on the curved surface of the cone. Obviously, the one view shown, and the elements, cannot be drawn without a full view. It often occurs in practice that it is inconvenient for various reasons, such as lack of space on the paper or too small a drawing board, to employ the regular projection method of transferring points from the full view to one of the views on a principal plane. In such cases, it may be more convenient to draw two full views, one for each of two views on principal planes, as is shown in Fig 11 (b). When this method is adopted, the greatest care must be exercised to locate corresponding points of the two full views correctly in reference to the axes of the principal planes and traces of the auxiliary planes. In Fig. 11 (b), the full view A is divided into eight equal parts so located that the two points 6 and 8, 1 and 5, and 2 and 4 lie on the same projection line drawn to the trace $a\ b$. To find the location of the points 1 and 5 of the full view A on the full view B, it is necessary to bear in

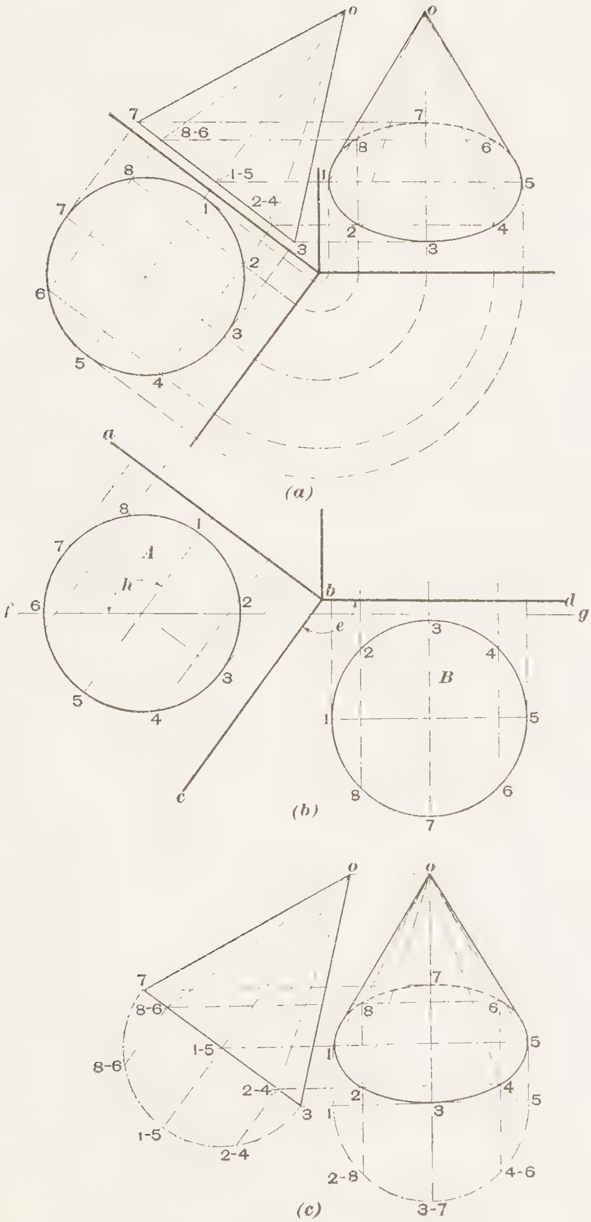


FIG. 11

mind that the view A is turned through the angle e between the trace $b\,d$ and the revolved trace $b\,c$. This brings the line *1–5* of the view A from a position perpendicular to the trace $a\,b$ into a position parallel to the trace $b\,d$, as shown in the view B. To see this more clearly, draw a line $f\,g$ parallel to

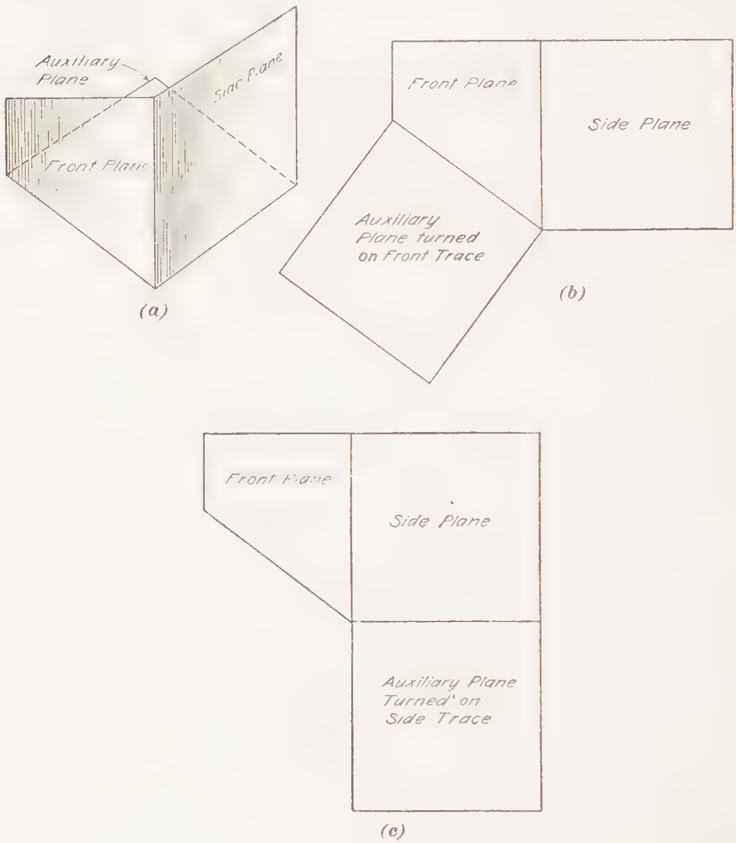


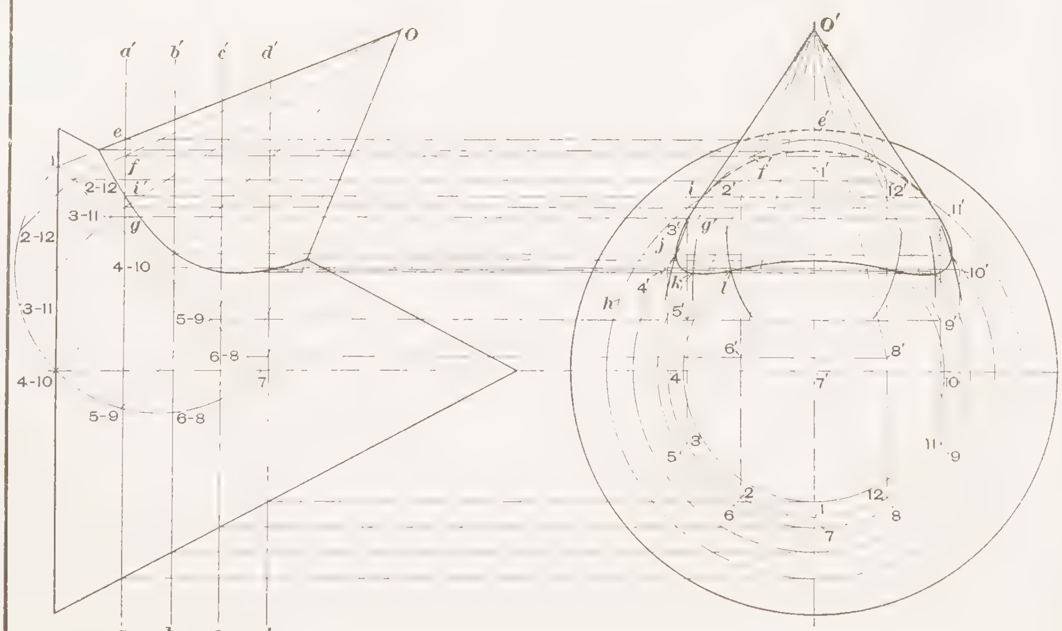
Fig. 12

the trace $b\,d$ through the center of the view A. Then, because *1–5* is parallel to $b\,c$ and $f\,g$ parallel to $b\,d$, the angles h and e are equal; hence, turning the view A around its center through the angle h brings the line *1–5* to a position where it coincides with the line $f\,g$; that is, it is parallel to the trace $b\,d$.

17. Instead of working from two complete full views, it is sometimes possible to work from half full views. When a full view is symmetrical in respect to a line passing through its center at right angles to the trace across which projecting is done, half views can be used. Thus, in Fig. 11 (*b*), the semicircle *3–4–5–6–7* of the view *A* and the semicircle *1–8–7–6–5* of the view *B* can be used; Fig. 11 (*c*) shows the application of this method to the same case that was presented in (*a*).

18. In working from two full views it must be clearly borne in mind that the two full views represent two different positions of the same auxiliary plane, which has simply been turned first around one and then around another of its traces. Thus, in Fig. 12 (*a*) are shown the planes of projection for the case illustrated in Fig. 11. In Fig. 12 (*b*) the planes have been turned into the plane of the drawing, with the auxiliary plane turned on its front trace to allow drawing the full view *A*, Fig. 11 (*b*). In Fig. 12 (*c*) the auxiliary plane is turned on its side trace to permit drawing the full view *B*, Fig. 11 (*b*). When this is kept in mind the position of the second full view in reference to the first full view can be readily determined.

19. Problem 10. Sheet III.—The curved surface of a right cone having a vertical height of $4\frac{3}{4}$ inches and whose base has a diameter of 5 inches is intersected by another cone in such a manner that the center lines of the two cones intersect at the center of the base of the first cone at an angle of 45°. The smaller cone has a vertical height of $3\frac{1}{2}$ inches and its base has a diameter of 3 inches; the base is at a distance of $1\frac{1}{2}$ inches from the center of the base of the large cone, measured along the center line of the small cone. Draw a front view and side view, the side plane being at the right of the front plane. Make the drawing so that the center lines of the two cones are in a plane parallel to the front plane and the center line of the large cone is parallel to the horizontal plane. The vertex of the large cone is toward the side



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plane, and the small cone points toward the horizontal and side planes.

Solution.—Referring to the reduced copy of Sheet III, Exercise III, at a distance of $4\frac{1}{2}$ inches from the upper border line and parallel thereto draw the projection of the center line of the large cone. At a distance of $\frac{1}{2}$ inch from the left border line, intersecting the projection of the center line first drawn, and at an angle of 45° to it, sloping upwards to the right, draw the front projection of the center line of the small cone. Draw the front projections of the two cones. Draw a half full view of the base of the small cone and divide it into any convenient number of equal parts, say six. Project these points of division to the front projection of the base and draw the front projections of the corresponding elements of the small cone.

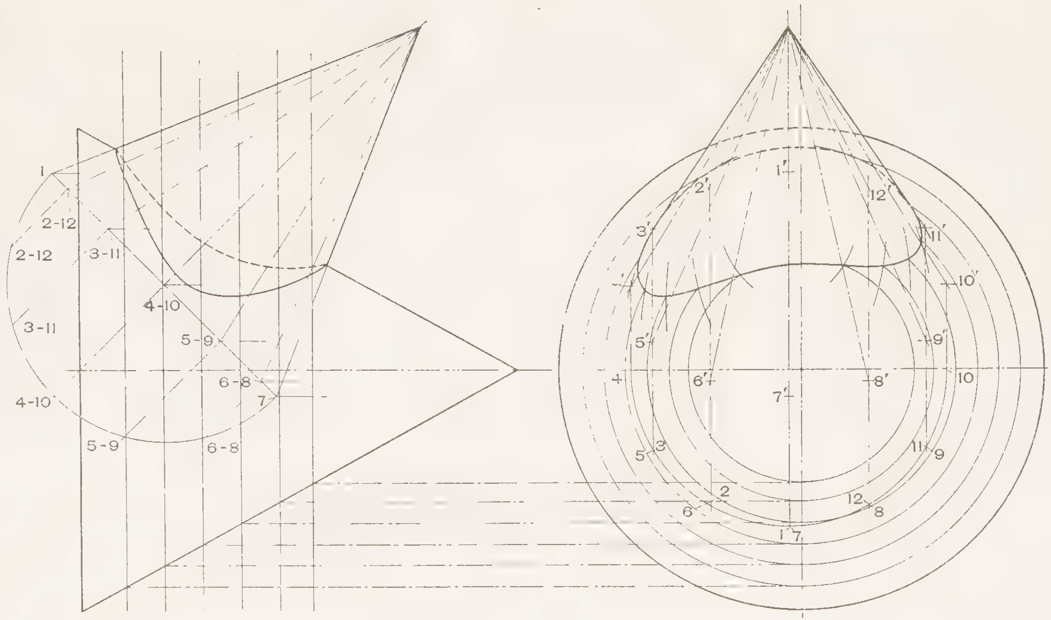
Draw the circle representing the side projection of the large cone so that its center is at a distance of $2\frac{11}{16}$ inches from the right border line. From the same center draw a half full view of the base of the small cone, dividing it into six equal parts. By projecting upwards from these points of division and projecting across from the front view, determine the side projections $1'$, $2'$, etc. of the intersections of the elements with the base of the small cone. The side projection O' of the vertex of the small cone having been found, draw the side projections $O'\,1'$, $O'\,2'$, etc. of the elements of the small cone.

Through the front projection of the two cones pass a number of cutting planes in any convenient direction. In the solution presented, the cutting planes, as indicated by their traces $a\,a'$, $b\,b'$, etc., were taken parallel to the base of the large cone and perpendicular to the front plane, in order that the side projections of their intersections with the large cone may be circles. Although, in the solution presented, for the sake of clearness, almost the entire circumference of these circles is shown, in practice short arcs crossing the probable side projection of the miter line are all that are required.

The next step is to find the side projections of the intersections of the cutting planes with the small cone, which is done in the manner already explained in connection with the problems relating to finding the sections of cones. Thus, to find the side view of the section at the cutting plane whose front trace is $a\,a'$, project the intersections e, f, g of the trace $a\,a'$ with the front projections $O\,1$, $O\,2$, $O\,3$ of the elements to the side projections $O'\,1'$, $O'\,2'$, $O'\,3'$ of the elements, thus obtaining three points e', f', g' on the line of intersection. Through the points e', f', g' draw an elliptic curve, intersecting the circle h at i; the point i is the side projection of a point on the miter line. To find the front projection, project i to the front trace $a\,a'$, the projection line cutting this trace at i'; the point i', then, is the front projection of the point whose side projection is at i. In the same manner, determine the side projections j, k, l, etc. of other points of the miter line and then their front projections; finally, through the points found trace the two projections of the miter line.

It will be obvious that the more cutting planes can be chosen, the more points in the projections of the miter line are determined. The question of how many cutting planes to choose depends for its answer entirely on the judgment of the draftsman.

20. Problem 11. Sheet IV.—The curved surface of a right cone having a vertical height of $4\frac{1}{2}$ inches and whose base has a diameter of 5 inches is intersected by another right cone having a vertical height of $3\frac{3}{4}$ inches and a base diameter of $3\frac{1}{4}$ inches. The center line of the small cone makes an angle of 45° with the base of the large cone; the center line of the small cone penetrates the base of the large cone at a distance of $\frac{1}{8}$ inch from its center. The base of the small cone is at a distance of $1\frac{1}{4}$ inches from the base of the large cone, measured along the center line of the small cone. Draw a front and a side view, the side plane being at the right of the front plane. Draw the views so that the center line of the large cone is parallel to the horizontal and front planes,



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and so that the center line of the small cone is in a plane parallel to the front plane and between the front plane and the center line of the large cone. The vertex of the large cone is nearest the side plane; the vertex of the small cone points toward the horizontal and side planes.

Locate the projection of the center line of the large cone $4\frac{1}{2}$ inches from the upper border line; locate the front projection of the base of the large cone $\frac{7}{8}$ inch from the left border line; and locate the center of the side projection of the same cone $2\frac{11}{16}$ inches from the right border line.

DEVELOPMENT OF SURFACES

FUNDAMENTAL PRINCIPLES

INTRODUCTION

DEFINITIONS

1. A development is a drawing in which a full view of all the surfaces of a solid is represented. Whenever a development is to be drawn (except in the case of solids of very simple form), one or more, usually two, projection drawings must first be made. Since the location of the various points in a development is dependent on their corresponding position in the projection drawings, the importance of the projection and the necessity for accuracy in its construction are clearly seen. If a solid is bounded entirely by plane surfaces, its development can be accomplished by projecting their full views, and assembling these in their proper relation.

A solid is said to be developed when all surfaces composing it are represented on one plane and in such relation to one another that, if formed or bent up, they will constitute the solid represented by the projection drawings from which the development was made. Such a representation is called a **development,** or a **pattern,** the process of laying out the pattern being termed *developing the surfaces of the solid*.

It is to be noted that in the study of the development of surfaces here presented the surfaces are considered to have no thickness, and it is assumed that edges butt together. In

practice, however, for articles formed of thin sheet metal it is necessary to allow where required, outside of the pattern, a certain width of metal for the purpose of joining the edges in various ways. For thicker metal, another allowance has to be made on the pattern itself to take care of the gain or loss in length that occurs in bending the metal to the required form. These allowances will be treated of fully in their proper place; to repeat, all problems here given assume butt joints and surfaces of no thickness, in order to make it easy to understand the principles involved in developing surfaces.

2. When it is desired to produce a pattern requiring a combination of several surfaces that are adjacent in a solid, such surfaces must be drawn in the same relation to one another in the development. The surfaces of a solid when thus combined in a pattern, or development, bear the same relation to one another that they would if they were considered as being *unfolded* or *unrolled*.

It will be seen from the foregoing that, were all solids bounded by flat, or plane, surfaces, the subject of developments would present no new problems; it would be necessary merely to study the relation of surfaces to one another, project their full views, and carefully redraw them in the pattern in the same relative position.

3. A thorough knowledge of projection is absolutely necessary to understand the operations involved in developing the surfaces of a solid. The position of the several points located in a drawing and their corresponding location on the object itself must be definitely fixed in mind. Each line must be determined in its relation to the other lines of the drawing and its location definitely ascertained; the surfaces, also, must be treated in a similar way. A person must picture to himself the completed object as it will appear when the surfaces laid out on the drawing board in the development are formed up in their final relation to one another.

In projection drawing, the surfaces of the solid are represented as being in their proper position; in the develop-

ment, the same surfaces are represented as being developed or spread out on the surface of the drawing board, or sheet of metal, or other material from which the solid is to be made.

ACCURATE AND APPROXIMATE DEVELOPMENTS

4. An accurate development may be drawn for the plane surfaces of any solid, or for surfaces having, when related to a given line on such surface, a curvature in one direction only. In general, it may be stated that any solid may be accurately developed on whose surfaces it is possible to lay a straightedge, in continuous contact, in any one direction. Thus, considering a cylinder, it will be seen that, if the straightedge is resting on the surface parallel to the axis of the cylinder, it will remain in contact at all points. If, on the other hand, the straightedge is resting on the curved surface and is not parallel to the axis of the cylinder, the surface will be in contact at a single point only. However, the fact that it is possible to place the straightedge in continuous contact on the surface shows that such surface is capable of accurate development.

The same rule applies to solids of irregular form. There are certain forms whose surfaces, owing to their curvature in several directions, are not capable of being thus laid out on a flat surface; that is, are not capable of being developed. On the surfaces of solids of this class—the sphere, for example—it will be found impossible to lay the straightedge in contact in any direction. For, if placed on such a surface, there will be but one point of contact—that at the point of tangency. Tangential contact indicates that development can be accomplished in only an approximate way. For purposes of development, then, it is convenient to separate all solids into two general classes according to the result obtained in developing their surfaces. These two classes are: solids whose surfaces admit of accurate development and solids whose surfaces admit only of approximate developments. Approximate developments are, however, frequently so nearly accurate for practical purposes that the kind of solid

is more clearly marked by the method of developing its surface than by the result obtained by the development.

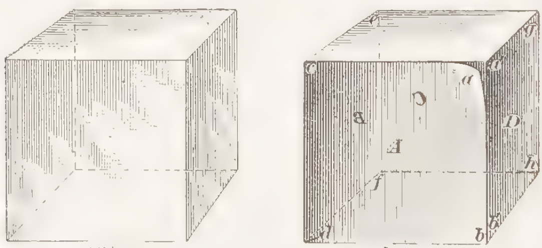
Solids whose surfaces are capable of accurate development are of frequent occurrence in practice. To this class belong all prismatic, cylindrical, and conical forms, whether of regular or irregular geometrical form.

The sphere and other solids whose surfaces have a curvature in two or more directions are examples of objects susceptible to only approximate development.

METHODS OF DEVELOPMENT

SOLIDS DEVELOPED ON PARALLEL LINES

5. There are three distinct methods in common use by means of which patterns are produced for solids whose surfaces are capable of accurate development. It is advisable, therefore, to separate the different varieties of these forms into three general divisions, in order that their development may be studied in a systematic manner. This classifica-



(a) (b)

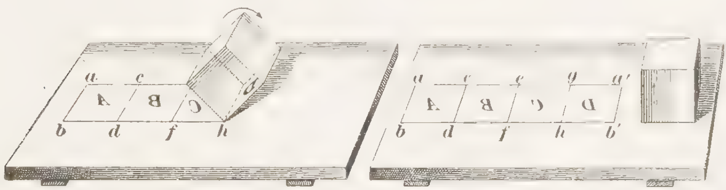
Fig. 1

tion may be made by studying the manner in which the surfaces of these solids would be unrolled or spread out if done by rolling the solid on a flat surface.

A convenient illustration of the manner in which the surfaces of a solid will appear when unrolled as above indicated may be found in the following example, which serves at the

same time to define a property peculiar to solids of a certain form. Let the continuously adjacent surfaces of the prism shown in Fig. 1 (*a*) be carefully covered with thin paper, as in Fig. 1 (*b*). Denote each of the four surfaces by a letter, as *A*, *B*, *C*, and *D*, and further designate the edges of the prism by the letters *a b*, *c d*, *e f*, and *g h*. As the ends of the paper covering meet at the edge *a b*, that edge of the surface *D* may be denoted by the letters *a′ b′*, as shown in Fig. 1 (*b*). Assume now that the prism is laid on the drawing board, the surface *A* face down, and the paper covering removed by turning the prism over and over, the paper remaining on the surface of the drawing board, as shown in Fig. 2 (*a*) and (*b*).

Two important principles relating to developments by rolling are here demonstrated. First, as will be seen from



(*a*) (*b*)

FIG. 2

Fig. 2 (*b*), the edges *a b*, *c d*, *e f*, *g h*, and *a′ b′* are all parallel to one another. This is true both in the development and on the solid, as may be readily seen, the only difference being that on the solid certain of the lines are in different planes, while in the development they are all in the same plane. Second, it will be noted, as indicated by the reversed letters shown in Fig. 2, that the *outer* surface of the paper covering in Fig. 1 (*b*) corresponds to the *under* surface in Fig. 2 (*b*). From this it follows that if a development is made by the method just described, positions indicated on any surface of a solid, as shown in a projection drawing, are reversed when shown in the development of the solid.

6. The same treatment of the cylinder is found to produce results closely resembling those shown in the case of the

prism. The cylinder is represented in Fig. 3 (a) as covered with paper, a number of lines being ruled on the covering parallel to its axis, as shown at $c\,d$, $e\,f$, etc. The paper is shown unrolled in Fig. 3 (b), and it will be observed that not only the outer edges $a\,b$ and $a'\,b'$ are parallel to each other, but that all other lines parallel to the axis of the solid appear in the development parallel to one another and to the edge lines $a\,b$ and $a'\,b'$.

7. Instead of rolling along a flat surface the object to be developed, as was done in the cases illustrated by Figs. 2 and 3 and explained in Arts. **5** and **6**, the imaginary paper covering may be unwrapped from the object and laid down on a flat surface so that the under side of the paper covering will be in contact with the flat surface. When this is done,

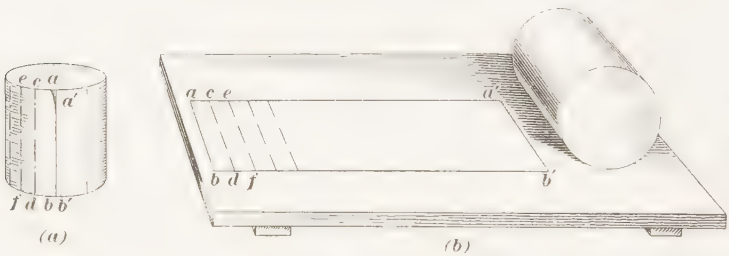


Fig. 3

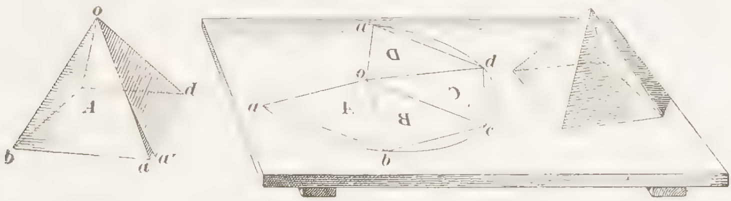
positions indicated on any surface of a solid are *not* reversed when shown in the development. This point is so important that it must be clearly kept in mind.

Either the method of rolling a solid along a flat surface, or of unwrapping an imaginary covering from the solid and placing it as described, may be used in practice; in forming the article from the pattern it must be clearly kept in mind, however, which method was used, since the direction in which bends are made to form the article are exactly opposite in character with the two methods. Thus, considering Fig. 2, the right-angled bends at the edges $a\,b$, $c\,d$, etc. would have to be upwards, and by the second method the bends would have to be downwards; that is, in exactly the opposite direction. To clearly see this, wrap a piece of paper around a square

stick of wood or some other similar object, and after unwrapping it lay it down on a flat surface first with one side up and then with the other. It will be seen at once that the direction in which the paper must be folded to wrap it around the object again will be opposite in relation to the surface of the paper that is uppermost in each case.

SOLIDS DEVELOPED ON RADIAL LINES

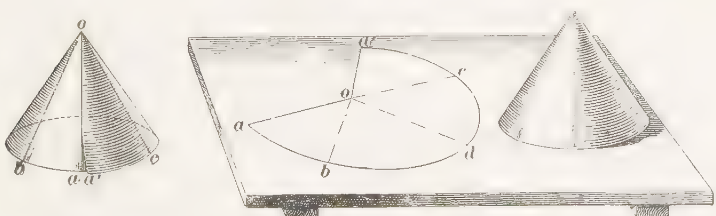
8. When a pyramid imagined to be covered with paper, as shown in Fig. 4 (*a*), is rolled on a drawing board, as shown



(*a*) (*b*)

FIG. 4

in (*b*), it will be found that the lines on the paper that denote the inclined edges converge to a point *o*, which defines the position of the vertex of the pyramid. The same may be said of the cone, illustrated in Fig. 5 (*a*) and (*b*). If lines corresponding to its elements are first indicated on the surface of the cone, it will be found, when the covering is



(*a*) (*b*)

FIG. 5

unrolled, that these lines also converge to a point, as in the case of the edges of the pyramid.

It was found possible in the case of the prism and cylinder to institute a system of obtaining developments based on parallel lines; in a similar manner, it is quite evident in this case that a system dealing with radial lines should produce like results. Since, in projection drawing, the elements of the cone are known to be factors in determining the position of points on its surface, it may be readily conceived that their use may be adapted to developments. This is the case; and a second general division of solids is thus made, consisting of those forms whose surfaces may be developed on *radial lines*. Included in this division are all regular tapering solids and such irregular forms as are derived from regular solids.

SOLIDS DEVELOPED BY TRIANGULATION

9. There are many forms of irregular surfaces to which the test of the straightedge may be applied and the conclusion thereby reached that their surfaces admit of accurate development. It may also be concluded that neither of the two former methods is applicable, for neither parallel lines nor a series of radial lines may be drawn on their surfaces. Many of these solids are not of such a shape as to admit of their being either turned or rolled on a plane surface. It is found, however, that on every such surface, series of straight, or approximately straight, lines may be drawn in certain directions, forming triangles.

On such irregular surfaces it may happen that no two of the triangles thus drawn on the solid, or represented—either correctly or foreshortened—in the projection drawings, will lie in the same plane or be equal to each other. Since it is possible to obtain full views of these triangles, they may be reproduced on the flat surface of the drawing paper in their correct size.

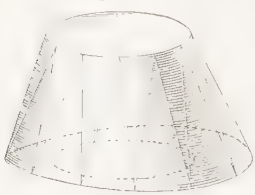


FIG. 6

In Fig. 6 is shown an irregular solid whose curved surface cannot be developed either by parallel lines or by radial lines. This figure shows, however, in perspective, a series of triangles

drawn on its curved surfaces; from two projection drawings of the solid, containing the projections of these triangles, a full view of each triangle is readily constructed. These full views of the triangles are then arranged on the flat surface where the development is made in the same relation to one another as they bear on the solid, and thus a series of points on the outline of the developed surface are obtained.

To sum up, the third general division consists of solids whose surfaces are developed by triangulation; that is, by means of triangles.

CHOOSING THE METHOD OF DEVELOPMENT

10. In practice, a person does not actually apply the test of the straightedge in reaching a conclusion as to whether the surfaces of a solid may be accurately or approximately developed. Nor does he roll the object on the drawing board in order to determine whether the method by parallel lines or one of the other methods is to be used. As a matter of fact, he seldom has a model to work from, and, therefore, could not apply such a test if he so desired. But as he studies the drawings and imagines the positions of the surfaces as they will appear in the completed object, he is enabled to apply the tests as effectually, in his imagination, as if the tests were made with a straightedge. In the same imaginary way, also, he assigns the solid to the general division to which it properly belongs, and thus decides as to the method he will use in the development of its surfaces.

A little practice will enable a person to classify the variously formed objects and to select the method to be applied in any given case. A very important part of development of surfaces consists in being able to recognize in various irregular objects those forms that may be only a part of some regular solid. In other words, a person must learn to establish in his own mind the connection between complete and perfectly formed solids and those objects in which only a part of the solid may be represented. The method of development is, of course, the same in both cases, but, as a matter of fact, the operations are usually more complicated in cases where

the solid is only part of a regular solid. Especially is this true of conical forms, or those developed on radial lines. Frequent illustrations of this principle may be found in

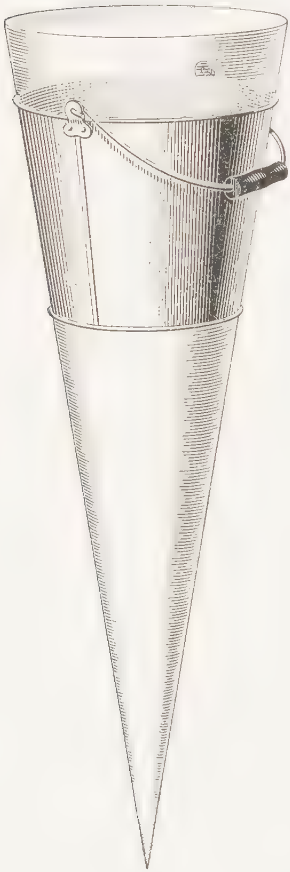


FIG. 7

FIG. 8

commonly occurring objects. The flaring pail shown in Fig. 7 is seen to be a part, or frustum, of a cone, the completed cone being indicated by the light shading in the illustration.

Another instance is found in the measure shown in Fig. 8. Here are two intersecting cones: a regular frustum of one forms the body of the measure; and an irregular frustum of the other—an inverted cone—forms the lip of the finished article.

APPLICATION OF PRINCIPLES

DEVELOPMENT BY PARALLEL LINES

GENERAL DIRECTIONS

11. A number of exercises, each consisting of several sheets, on each of which are one or more problems, are to be drawn by the student and sent to the International Correspondence Schools for correction. The sheets on which all the exercises are to be executed may be about 9 in. × 12 in. outside measurement, and must be 8 in. × 11 in. within the border lines. The different lines on the drawings may be inked in or not, as preferred. Any kind of paper may be used; however, a white paper having a hard, smooth surface will permit of the greatest accuracy, and is recommended.

There will be two or more cases of each problem, of which the solution of the first case will be given quite fully; the solution in the other case or cases will be similar to that of the first, and the drawing is to be made by the student without further explanation. All problems on each sheet are to be drawn.

Having completed the several sheets of an exercise, the number of the exercise, the title of the Paper, and the number of the sheet is to be written on each sheet at the top and outside of the border line. At the bottom of the sheet and outside of the border line is to be written the date the drawing was completed, the name of the student, the class letters, and the number. Thus, suppose the drawing is the first sheet of Exercise I, *Development of Surfaces*, and that it was completed May 14, 1912; suppose the name of the

student is John Smith, his class letters are DCA, and his number is 1,280,679. Then, by consulting the reduced copy of Sheet I, Exercise I, on page 17, the form in which the information called for is to be written can be seen. On the back of each sheet of each exercise is to be written the full address of the student. Then mail all the sheets of each exercise, one exercise after the other, to the International Correspondence Schools, Scranton, Pa., for correction. Do not mail single sheets; mail only a complete exercise.

The greatest of care must be exercised to do the work neatly and accurately. Reference letters appearing on the reduced copies of the sheets are to be omitted.

Those dimensions given in problems or their solutions that relate to the location of points or lines in reference to the border lines have nothing to do with the solutions of the problems; they are given to prevent overlapping of the different drawings, and thus obviate needless work.

EXERCISE I

12. It has been already stated that the making of projection drawings is the first step toward obtaining a pattern for the surfaces of any solid. The solid in question, whenever possible, should be shown in these drawings in such a position that all lines needed for the development will show in their true length. Several views may have to be drawn, although two views will usually be sufficient. In some cases the object may be so shown that needed dimensions may not be readily obtained. In such cases, the dimensions must be obtained from additional full views or by finding the true lengths of the foreshortened lines by triangulation. Referring now to objects susceptible to development by parallel lines, they should preferably be drawn in such a position in reference to the principal planes of projection that those edges needed in developing the surfaces are parallel to at least one plane of projection, in order that they will show in their true length on that plane. In other words, the object should be drawn in what is commonly called **a right posi-**

tion. Thus, the projection drawings of a cube, for instance, should be made with the surfaces of the cube parallel to the horizontal, front, and side planes, when the edges also will be parallel to those planes, and hence show in their true length on the several views.

13. From the several views of a projection drawing of an object to be developed by parallel lines the width of each surface may be readily ascertained. The total width of all these surfaces—the distance around the solid—is called the **girth** of the solid. In case the solid has a curved surface, its girth is found by spacing with the dividers the outline in that view, or by calculation. The girth of a cylinder, for example, is equal to the length of the circumference of a circle that represents the base of the cylinder.

When a distance corresponding to the girth of any solid is laid off on a straight line on a flat surface, such a distance is called a **stretchout** for the development, or pattern. The line on which the stretchout is laid off is called the **stretchout line.** This stretchout is then marked off by a series of points, the points representing the places at which the line would be bent if formed up to correspond with the outline of the solid represented in the view from which the distances were taken. In the case of curved surfaces, a number of points are located on the outline. This is usually done by dividing the outline into a number of equal spaces in the same manner as in projection drawing; an equal number of spaces is then stepped off on the stretchout line, and in all cases their combined length is equal to the girth of the solid. An important point to be observed is that the points thus located on the stretchout must be in a position on the line corresponding to that relatively occupied on the solid. It is to be noted that on the solid the line denoting the stretchout, that is, the **girth line,** must be at right angles to the parallel lines of the solid.

14. For the purpose of giving a better explanation of the use of the stretchout, the development of a cube is presented, step by step, in Figs. 9 to 11, inclusive. A repro-

duction of this development should be made in accordance with the following instructions, although the drawing is not to be sent to the Schools for correction.

The top view and front view shown at the left in Figs. 9 and 10 are drawn first. Next, in any convenient location and in any convenient direction, draw a straight line, as $M\ N$, Fig. 9. On this straight line locate a point w in any convenient place. This point w may correspond to any of the horizontal edges represented on the front view by A, B, C, and D. In unfolding the surfaces of the cube, the point w will here be considered as representing a position on the edge A. The surfaces are represented in their regular order in the development, that is, in the order in which they appear on the solid itself; first, the surface represented in the front

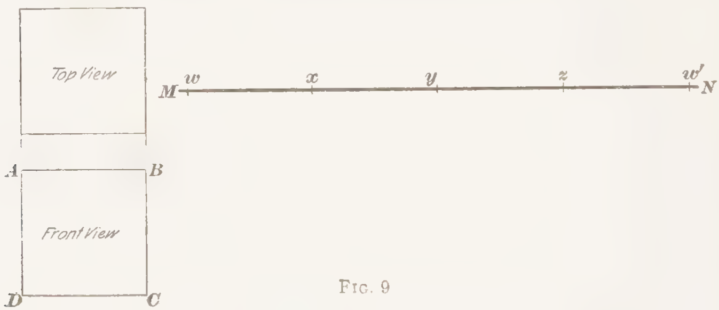


Fig. 9

view by $A\ B$, then $B\ C$, $C\ D$, and $D\ A$, in their order as shown. The dividers may, therefore, be set to a distance equal to the length of the side $A\ B$, and, since the sides of the cube are equal in length, the distances $w\ x$, $x\ y$, $y\ z$, and $z\ w'$ corresponding, respectively, to the sides represented in the front view by $A\ B$, $B\ C$, $C\ D$, and $D\ A$—are spaced off on the stretchout line $M\ N$.

That portion of the line $M\ N$ included between the points w and w' is the stretchout of the cube. A stretchout may be drawn in any position, but the girth line is invariably at *right angles to the parallel lines of the solid.* This statement does not imply that the line denoting the stretchout on a development must be at right angles to the projection of the parallel edges of the solid in its projection drawings from

which the development is made. When a development by parallel lines is made on a drawing board, it is usually con-

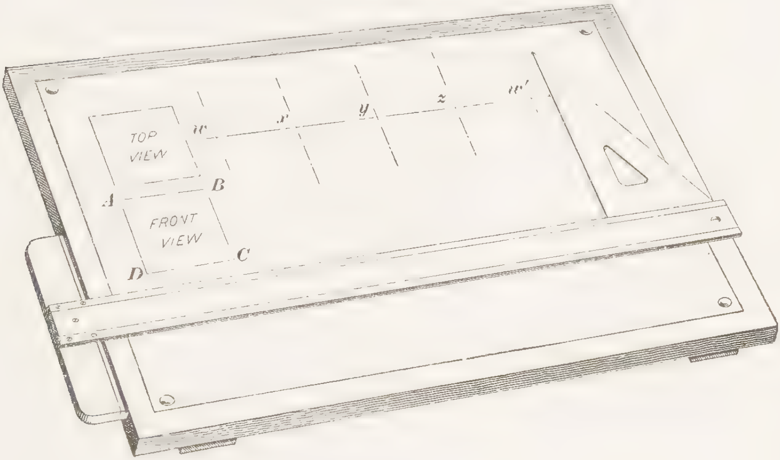


FIG. 10

venient to draw the stretchout at right angles to that projection of the parallel edges in which they show as lines, as the top view in Fig. 9, but it is not necessary to do so.

The next step is to erect perpendiculars to the stretchout line $M N$ that shall pass through the points w, x, y, etc. and be produced on both sides of the line. This may be done by means of the triangle, in connection with the **T** square, as in Fig. 10. The lines thus drawn are called *edge lines*, since they represent, in the development, those parts of the surfaces that would form the edges of the solid if the pattern

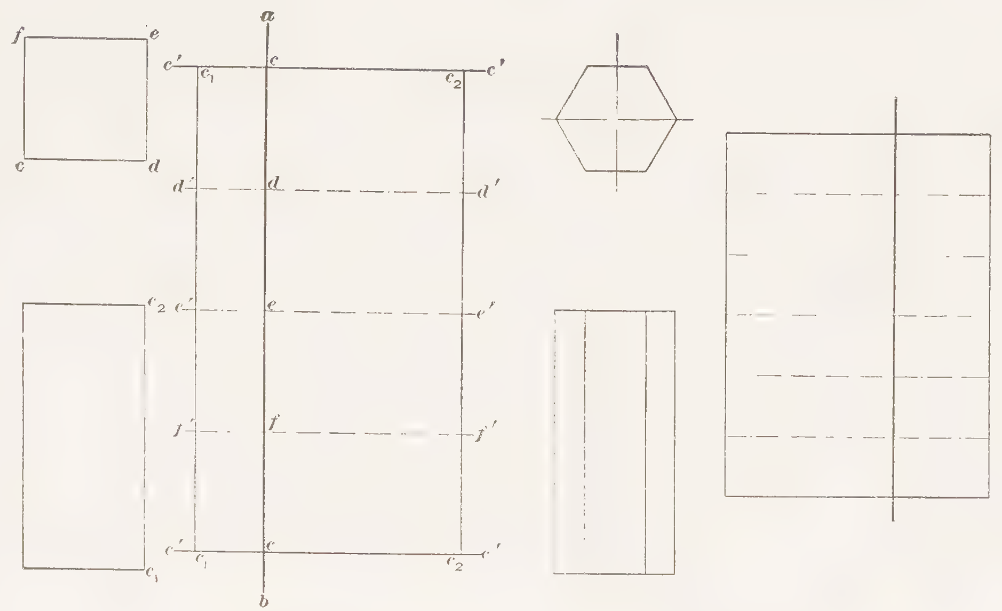
FIG. 11

were to be cut out and formed up to the shape indicated by the projections.

Next, the length of each of the horizontal edges shown in the top view is marked off on its corresponding edge line in the development. In the case of the cube, these horizontal edges are equal in length; hence, on one of the edge lines, as $a\,a'$, Fig. 11, lay off the length of a horizontal edge and through the two points defining this length draw straight lines $p\,q$ and $r\,s$ parallel to the stretchout. The rectangle $e\,f\,g\,h$ is the development of four sides of the cube. If desired, the other two sides, which, in this case, are the front and rear, may be added to any one of the four sides that were developed.

15. Problem 1. Sheet I.—Develop the large surfaces of the square prism shown in perspective in Fig. 12 and having the dimensions there given.

Solution.—Referring to the reduced copy of Sheet I, Exercise I, in any convenient position draw two views of the prism, one of which must show the long edges of the prism in their true length. It does not matter in what particular position the prism is imagined to be placed inside of the principal planes of projection; although in the solution presented, the prism has been so placed that its long edges are perpendicular to the horizontal plane, it may, if convenient, be placed in any other position in which one view will show the long edges in their true length. Strictly speaking, it is not absolutely necessary to place the prism within the principal planes so that its long edges will show in one view in their true length; it is possible to find their true lengths if they are inclined to all three principal planes, and hence show foreshortened in every view. This, however, in case of solids susceptible to development by parallel lines, involves unnecessary work. If it is decided to draw the prism in the position defined by its two projections appearing on the reduced copy of Sheet I, the left upper corner f of the top view may be located $\frac{1}{2}$ inch from the left and $1\frac{1}{4}$ inches from the upper border line. The lower edge of the front view may be located $1\frac{1}{4}$ inches above the lower border line.



Problem 1 Problem 2

May 14, 1912 John Smith, DCA 1,280,679

Next, in any convenient position, say parallel to the left border line and at a distance of 3 inches from it, draw a stretchout line $a\,b$; choose a point c on this line near its end a and in any convenient location, say $1\frac{1}{2}$ inches from the upper border line. From the point c lay off on the line $a\,b$ successively the widths $c\,d$, $d\,e$, $e\,f$, and $f\,c$ of the large surfaces of the prism, as taken from the top view. In this particular case, the prism being square, these widths are all equal. Through the points c, d, e, and f on the line $a\,b$ and at right angles to it draw the edge lines $c'\,c'$, $d'\,d'$, etc. On one of the edge lines, as the upper edge line $c'\,c'$, lay off the

FIG. 12

FIG. 13

distance $c_1\,c_2$ equal to the height $c_1\,c_2$ of the large surfaces, as given in the front view, locating the point c_1 of the development $2\frac{5}{16}$ inches from the left border line. Through the points c_1 and c_2 of the development draw straight lines $c_1\,c_1$ and $c_2\,c_2$ parallel to the line $a\,b$; the rectangle $c_1\,c_1\,c_2\,c_2$ is the boundary of the required development. It will be understood that the correct length of the edge lines is that between the lines $c_1\,c_1$ and $c_2\,c_2$.

Attention is once more called to the fact that the location of points and lines in reference to the border lines does not form part of the solution of the problem.

Problem 2.—Develop the large surfaces of the equal-sided hexagonal prism, with ends at right angles to the axis, shown in perspective in Fig. 13. This prism has a height of $2\frac{3}{4}$ inches and the ends have a diameter of $1\frac{1}{4}$ inches across corners.

Locate the center of the top view 2 inches from the upper border line and $4\frac{3}{8}$ inches from the right border line. Locate the bottom line of the front view $1\frac{1}{4}$ inches above the lower border line. The uppermost edge line of the development may be $2\frac{1}{8}$ inches from the upper border line, and its right boundary line $\frac{1}{2}$ inch from the right border line.

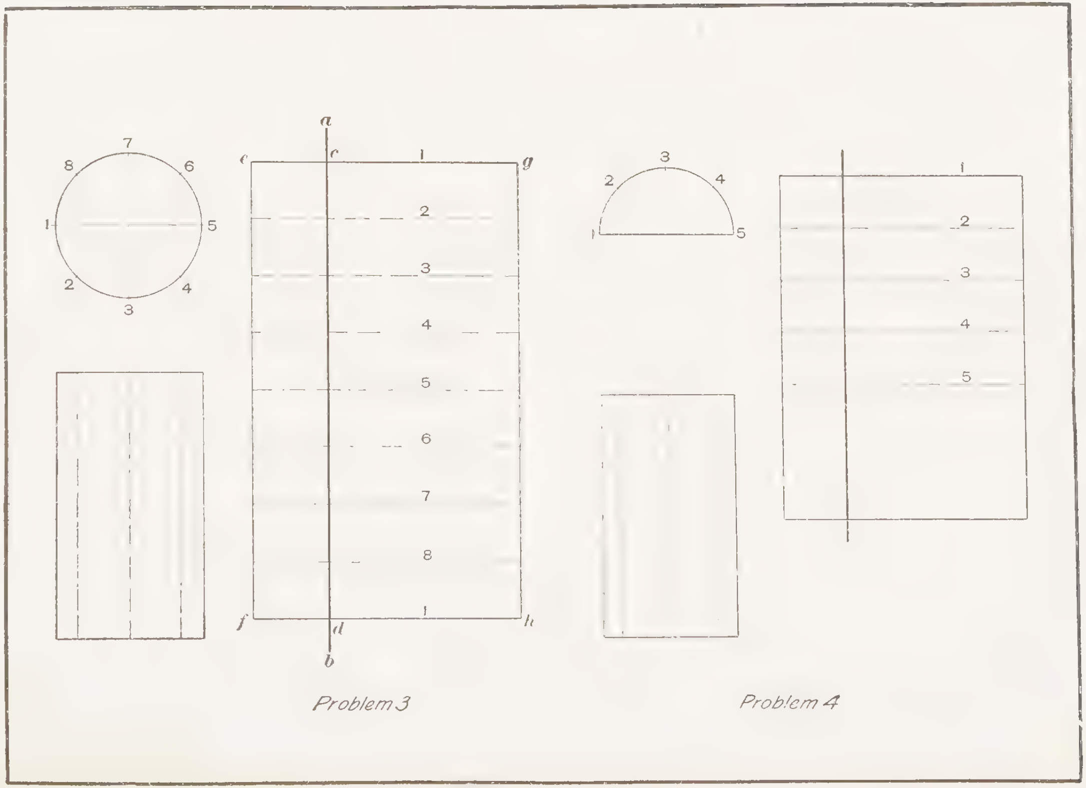
16. Problem 3. Sheet II.—Develop the curved surface of a cylinder having a diameter of $1\frac{1}{2}$ inches and a height of $2\frac{3}{4}$ inches, the ends being at right angles to its axis.

Solution.—It is readily seen that a development of the curved surface of a cylinder with ends at right angles is a rectangle having a width equal to the height of the cylinder and a length equal to its circumference, which is 3.1416 times the diameter.

In practice, the problem of developing a cylinder seldom presents itself in the simple form given; frequently the curved surface has one or more holes whose exact outline and position must be given on the development, and often the ends of the cylinder are not at right angles to the axis. In such cases the curved surface must be developed from elements drawn on it; in order to familiarize the student with this method it is given in the solution presented on the reduced copy of Sheet II, in preference to the simpler one of merely drawing a rectangle of the required dimensions.

Draw a top and a front view of the cylinder, locating the center of the top view $1\frac{1}{4}$ inches from the left border line and $2\frac{1}{4}$ inches from the upper border line. The bottom line of the front view may be located $1\frac{1}{2}$ inches from the lower border line. Choose a number of points on the circle representing the top view of the cylinder; although it is not necessary that these be equally spaced, it is very convenient in practice to space them thus. In this case the circle has

Exercise I *Development of Surfaces,* *Sheet II*



Date *Name of Student, Class Letters, and Number*

been divided into eight equal parts, the points of division representing the top views of elements. Draw these elements, which may be considered as edge lines, in the front view, projecting their position from the top view. It will be understood that these elements, being intersections of the curved surface of the cylinder with planes passing through the axis, are at right angles to the girth line conceived to be drawn on the solid. In some convenient position draw the stretchout line *a b*, and on it lay off the stretchout *c d*, equal to the circumference of the cylinder, or $3.1416 \times 1\frac{1}{2} = 4.71$ inches, locating *c* about $1\frac{5}{8}$ inches from the upper border line. Using dividers, divide the stretchout into eight equal parts and through the points of division, at right angles to the stretchout, draw the elements *1*, *2*, etc. On one of the elements lay off the correct length, taken from the front view, locating the point *e* $2\frac{1}{2}$ inches from the left border line. Draw the straight lines *e f*

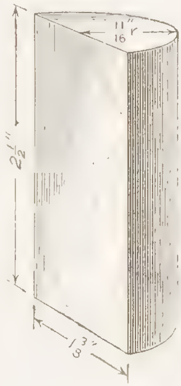


FIG. 14

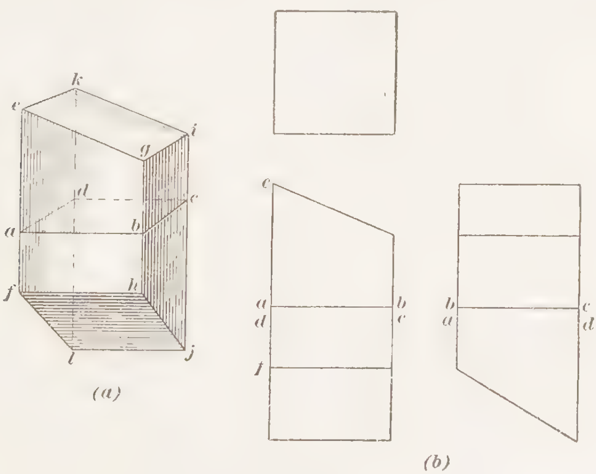


FIG. 15

and *g h* parallel to the stretchout, through the points laid off on the element; the rectangle *e f h g* is the required development.

PROBLEM 4. -Develop the curved surface and large plane surface of the solid shown in perspective in Fig. 14.

17. In many cases the parallel lines of a solid are interrupted by the intersection of another solid, or are cut by a cutting plane not at right angles to the axis, or what is the same thing, one or both ends are not at right angles to the parallel lines. A case in point is the rectangular prism shown in Fig. 15 both in perspective and by projection drawings, both ends being inclined to the vertical edges.

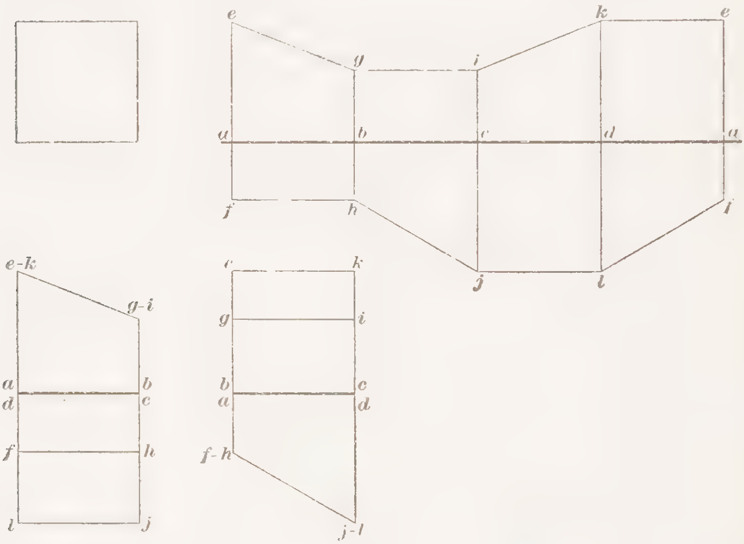


FIG. 16

The first step in the development is to pass a girth line *a b c d a* around the solid in some convenient location, as shown in Fig. 15 (*a*). This girth line is shown on the front and side views in Fig. 15 (*b*) by its projections. Consideration of Fig. 15 (*a*) shows that the girth line serves as a base from which the distance the ends of each edge are located can be measured. Thus, the ends *e* and *f* of the one edge are the distances *a e* and *a f* [see also the front view in Fig. 15 (*b*)] from the girth line.

The development of the prism shown in Fig. 15 is presented in Fig. 16. In some convenient position is drawn the stretchout line and on it are laid off the widths *a b*, *b c*, *c d*, and *d a* of the four vertical surfaces of the prism. The edge lines having been drawn at right angles to the stretchout *a a*, the distances *a e*, *b g*, *c i*, *d k*, and *a e*, taken from the front and side views, are laid off to one side of the stretchout. Likewise, on the opposite side of the stretchout the distances *a f*, *b h*, *c j*, *d l*, and *a f*, also taken from the front and side views, are laid off. The points *e* and *g*, *g* and *i*, etc. are now joined by straight lines, thus completing the development.

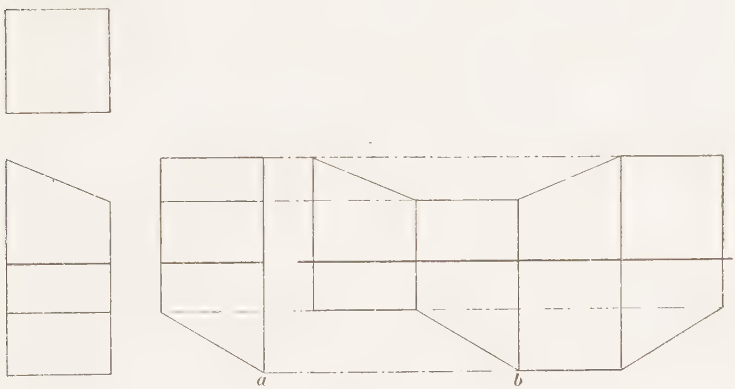


FIG. 17

The principle involved in measuring from a girth line is the most important one in developing a solid by parallel lines; in order that a person may firmly grasp this principle, it is recommended that a development similar to the one shown in Fig. 16 be made on a piece of paper and then be cut out. Next, fold it on the edge lines, having lettered all corners as in Fig. 16, and compare the folded development, which is now a geometrical solid, with Fig. 15 (*a*).

18. When a development of parallel lines is to be made on a drawing board, it is convenient to draw the stretchout at right angles to that view or views in which the parallel lines of the solid are parallel to a principal plane or planes.

This is shown in Fig. 17, which represents the development of the same solid that was presented in Figs. 15 and 16.

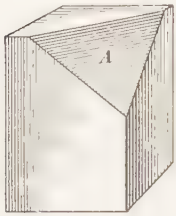


Fig. 18

When the stretchout is thus placed and the edge lines have been drawn, the length of the edge line can be projected across from the view or views to which the stretchout is at right angles, as indicated, using the **T** square. The projection lines used for this purpose, as $a\ b$ in Fig. 17, are called *developers*.

19. It often happens in practice that some surface or surfaces of a solid susceptible of development by parallel lines does not intersect all those parallel edges of the solid on which the development is to be made. A case in point is the solid shown in perspective in Fig. 18, where the surface A intersects only one of the four vertical edges of the prism. The method of developing such a solid is essentially the same as that previously given.

In Fig. 19 are shown at the left a top and a front view of the solid pictured in Fig. 18. The stretchout line having

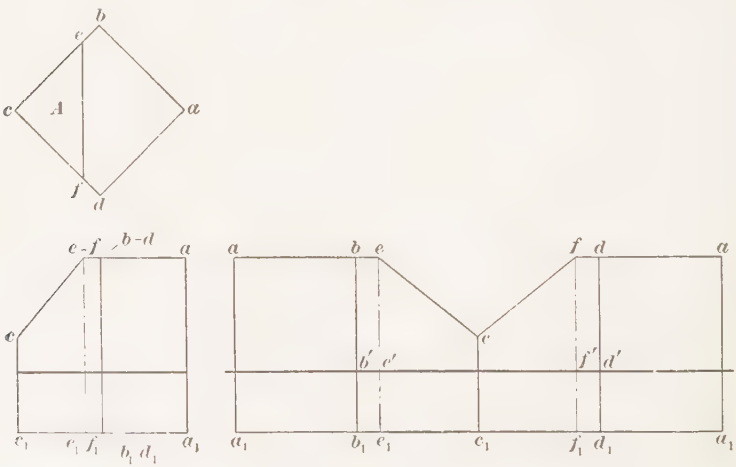


Fig. 19

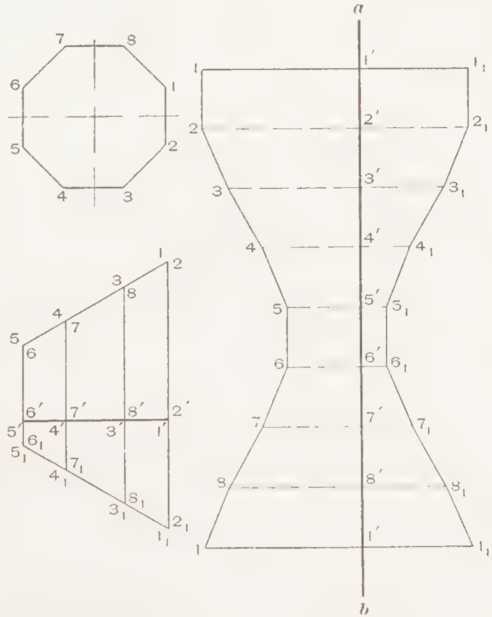
been drawn, the width of the four vertical surfaces, taken from the top view, is laid out on it and the edge lines are

drawn. Referring to the top view, it is seen that the surface A intersects the one vertical edge at c, and two upper horizontal edges at the points e and f. These two points obviously are the distances $b\ e$ and $d\ f$ from the edges b and d. Consequently, on the stretchout lay off $b'\ e' = b\ e$, and $d'\ f' = d\ f$. Through e' and f' draw parallel to the edge lines the lines $e\ e_1$ and $f\ f_1$, on which lines of the development will be located the corners e and f of the solid. As these lines $e\ e_1$ and $f\ f_1$ are between edge lines, they are termed *interedge lines*. Next, on the edge lines and interedge lines of the development, lay off to both sides of the stretchout the length of the edges and interedges, taken in this case from the front view, measuring from the girth line there shown. Join the ends a, b, e, c, etc., and a_1, b_1, e_1, c_1, etc. of the edge lines and interedge lines by straight lines, thus completing the development.

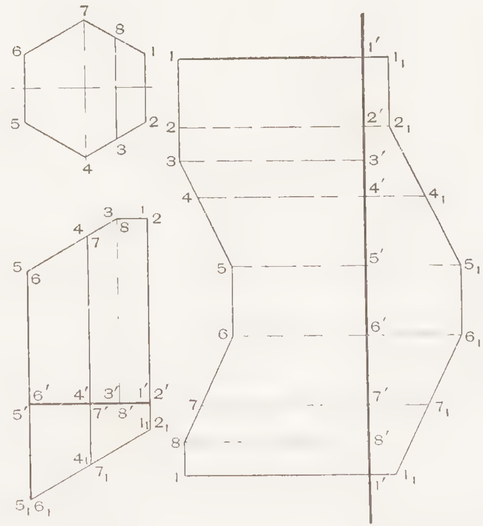
20. A general summing up of the instructions for developing solids by parallel lines is as follows:

1. Two views of the solid must be drawn in orthographic projection, preferably showing the solid with its parallel lines parallel to two of the principal planes.
2. The stretchout is obtained from the view on that plane to which the parallel lines of the solid are perpendicular; the length of edge lines and interedge lines is obtained from that view in which they show in their true length.
3. To indicate the width and relative position of the surfaces, points are located on the stretchout corresponding to the place of those points in a view that represents the surfaces on edge.
4. Edge lines and interedge lines are always at right angles to the stretchout.
5. Interedge lines, when necessary for the development, must be indicated on the projections as well as on the development.
6. The length of the outer edge lines in a complete development is equal.

When a stretchout is drawn at right angles to the parallel lines of a solid in a position to permit the use of developers:



Problem 5



Problem 6

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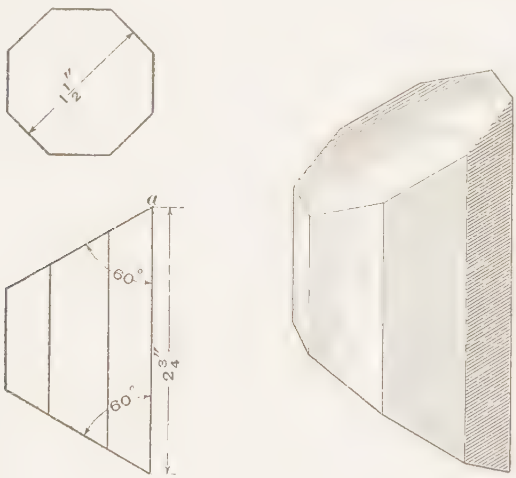
1. Developers are drawn from each edge or interedge represented in the projection drawing to the corresponding edge line or interedge line in the development. The position of points located on these lines is determined in a similar manner.

2. Interedge lines, when necessary for the development, must be indicated on the projection as well as on the development, and the same care exercised with the corresponding developers as with those drawn from edges to edge lines.

21. Problem 5. Sheet III.—Develop the eight sides of the octagonal prism with oblique ends shown to a reduced



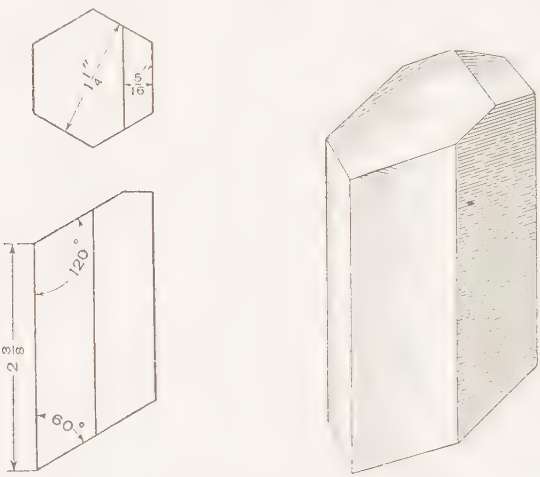
(*a*) Fig. 20 (*b*)

scale in orthographic projection in Fig. 20 (*a*), and also shown in perspective in Fig. 20 (*b*).

Solution.—Referring to the reduced copy of Sheet III, Exercise I, draw the top and the front view of the prism, locating the center of the top view $1\frac{1}{4}$ inches from the left border line and 2 inches from the upper border line. Locate the point a, Fig. 20 (a), $3\frac{1}{2}$ inches from the upper border line. In some convenient position, say $1\frac{5}{8}$ inches from the highest point of the front view, draw the girth line $1'$–$2'$–$3'$, etc. In

any convenient position and direction, say 4 inches from the left border line and parallel thereto, draw the stretchout line $a\,b$; beginning at some convenient point, say $1\frac{1}{2}$ inches from the upper border line, lay out the stretchout $1'-2'$, $2'-3'$, etc. Draw the edge lines and lay off their length on both sides of the stretchout, as taken from the front view. Complete the development by drawing the lines $1-2$, $2-3$, 1_1-2_1, 2_1-3_1, etc.

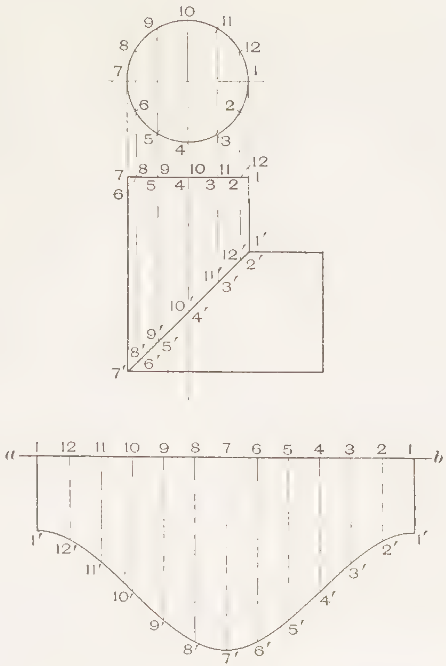
PROBLEM 6.—Develop the six sides of the prism shown to a reduced scale in orthographic projection in Fig. 21 (*a*)



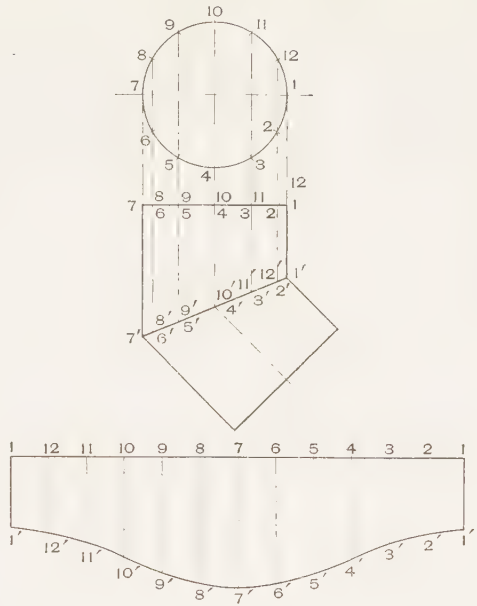
(*a*) FIG. 21 (*b*)

and in perspective in Fig. 21 (*b*); the ends of the prism are oblique.

Locate the center of the top view 2 inches from the upper border line and $4\frac{3}{8}$ inches from the right border line; locate the lowest point of the front view $1\frac{3}{4}$ inches from the lower border line. Draw the girth line about 1 inch from the lowest point of the front view, and draw the stretchout about $1\frac{1}{2}$ inches from the right border line.



Problem 7



Problem 8

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EXERCISE II

22. Problem 7. Sheet I.—Develop a pattern for the right-angled elbow shown in perspective in Fig. 22.

Solution.—Referring to the reduced copy of Sheet I, Exercise II, draw a top view of one end, and a front view of the elbow, which is composed of two equal cylinders with intersecting axes at right angles, so that in the front view by placing the axes in a plane parallel to the front plane, the miter line will be a straight line. The center of the top view may be placed $1\frac{1}{8}$ inches from the upper border line and 2 inches from the left border line. The upper edge of the front view may be placed 1 inch below the center of the top view. Divide the top view into any convenient number of equal parts, preferably a number divisible by 4; in the solution presented the circle has been divided into twelve equal parts and the points of division so arranged that all but two of the projection lines will pass through two points of division, as shown. Now, projecting from the top view, draw the projections of the elements *1–1′*, *2–2′*, etc. to the miter line. Since the front view was drawn with its axes parallel to the front plane, the projections of the elements are all parallel to the front plane and hence show the true length of each element.

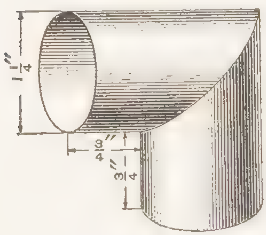
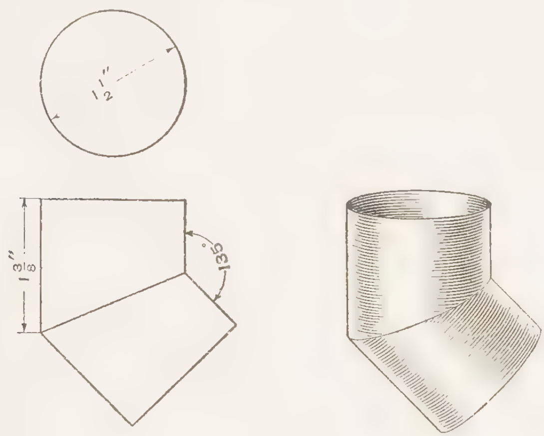


Fig. 22

In this particular case it is not necessary to draw a girth line on the front view; since the ends of the two cylinders are at right angles to their respective axes, the line *1–7* of the front view may be used as a girth line. In some convenient location, say parallel to the lower border line and 3 inches from it, draw the stretchout line *a b* and on it lay out the stretchout *1–1*, making it $1\frac{1}{4}\times 3.1416=3.93$ inches in length, locating the left end of the stretchout $\frac{3}{8}$ inch from the left border line. Divide the stretchout into twelve equal parts and draw the edge lines, on which lay off successively the

lengths *1–1′*, *2–2′*, etc. of the projections of the elements, as shown on the front view. Through the points *1′*, *2′*, *3′*, etc.



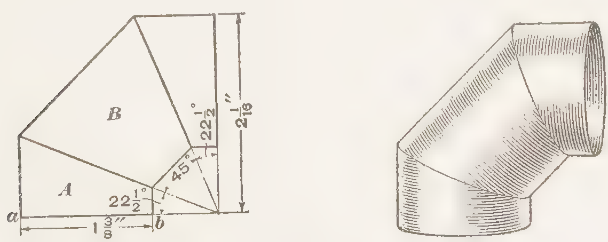
(*a*) FIG. 23 (*b*)

of the development trace a curve representing the miter line, thus completing the pattern.

PROBLEM 8.—Develop the pattern for the 45° elbow shown in orthographic projection in Fig. 23 (*a*) and in perspective in Fig. 23 (*b*). The two parts of the elbow are alike. The ends are at right angles to the axes of the cylinders.

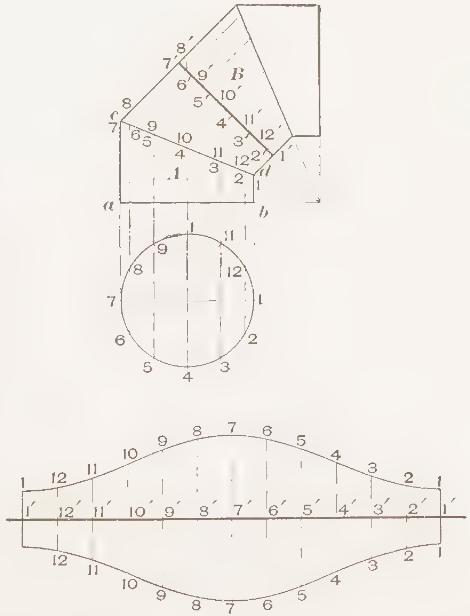
This elbow is called a 45° elbow because it changes by 45° the direction of the pipe to which it is applied.

Locate the center of the top view $1\frac{1}{4}$ inches from the upper

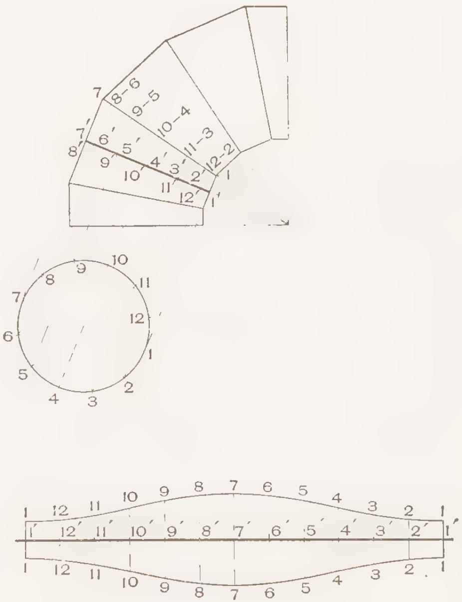


(*a*) FIG. 24 (*b*)

border line and $3\frac{3}{16}$ inches from the right border line; locate the upper edge of the front view $1\frac{1}{8}$ inches below the center



Problem 9



Problem 10

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of the top view. The stretchout may be drawn parallel to the lower border line and 3 inches from it; locate the right end of the stretchout about $\frac{5}{8}$ inch from the right border line.

23. Problem 9. Sheet II.—Develop the middle section of the three-piece 90° elbow shown in orthographic projection in Fig. 24 (*a*) and in perspective in Fig. 24 (*b*). The elbow is composed of three intersecting cylinders of equal diameter.

Solution.—Referring to the reduced copy of Sheet II, Exercise II, draw one view, say a horizontal view, so that the axes of the three cylinders will be parallel to the horizontal plane. Draw an end view of one of the cylinders in line with its horizontal view. The line $a\,b$, Fig. 24, may be drawn about 3 inches from the upper border line, locating its end a about $1\frac{5}{8}$ inches from the left border line. The center of the end view may be located about 1 inch below the line $a\,b$. Divide the front view into any convenient number of equal parts, say twelve, so arranged that all but two of the projection lines will pass through two points of division on the circle. Project the elements on the cylinder A; from their intersections with the miter line $c\,d$ draw corresponding elements on the center cylinder B. On the horizontal view draw a girth line, which must be at right angles to the elements. In case of a symmetrical solid like the central section of the elbow under discussion, where both ends make the same angle with the axis, it is convenient to draw the girth line midway between the two ends, as defined by the two miter lines; this, however, is not a necessity. Drawing the girth line in the convenient position named divides each element into two equal parts, and it is not necessary to measure each of the two parts separately when making the development.

In any convenient position, say $1\frac{3}{4}$ inches from the lower border line and parallel thereto, draw the stretchout line, and on it lay out the stretchout, which has a length of $1\frac{3}{8} \times 3.1416 = 4.32$ inches, at a distance of about $\frac{5}{8}$ inch from the left border line. Divide the stretchout into twelve equal parts; draw the edge lines and take the distance of their ends from

the stretchout from the horizontal view, measuring from the girth line to the miter line and laying off to both sides of the stretchout. Draw the two irregular curves through the points just laid off, thus completing the pattern.

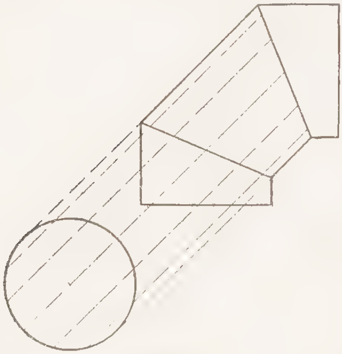
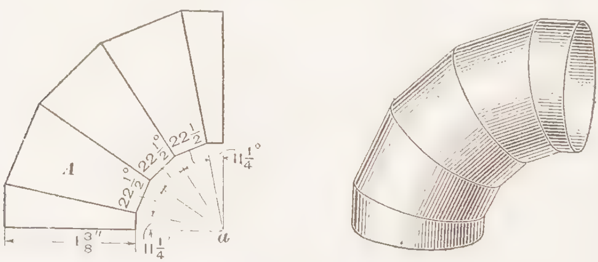


Fig. 25

24. Instead of finding the position of the elements on the central cylinder of Problem 9 in the manner shown on the reduced copy of Sheet II, Exercise II, they may be located in the way indicated in Fig. 25. There a view at right angles to the central cylinder has been drawn and divided into equal parts suitably located, from which view the elements have been projected.

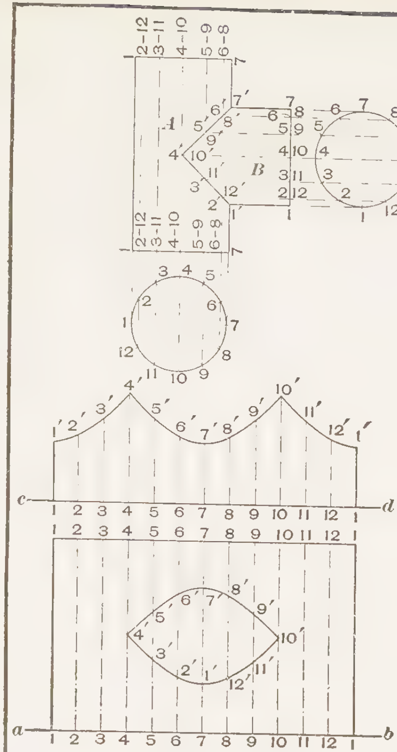
Problem 10.—Develop the section *A* of the five-piece 90° elbow shown in orthographic projection in Fig. 26 (*a*) and in perspective in Fig. 26 (*b*).

Locate the center *a* 3 inches from the upper border line and 2 inches from the right border line. The stretchout may be located about $1\frac{3}{4}$ inches from the lower border line and $\frac{7}{16}$ inch from the right border line.

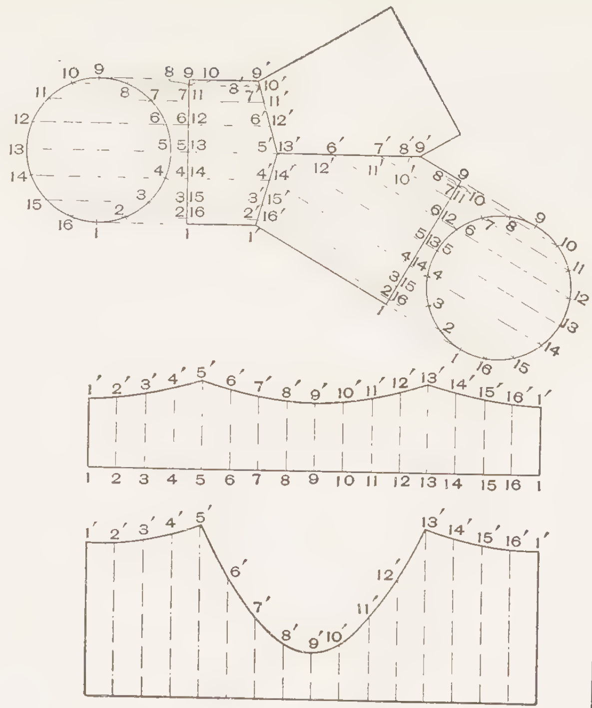


(*a*) Fig. 26 (*b*)

25. Problem 11. Sheet III.—Develop the surfaces of the **T** shown in Fig. 27. The **T** consists of two intersecting cylinders of equal diameter whose axes intersect and are at



Problem 11



Problem 12

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right angles and whose free ends are at right angles to the axes.

Solution.—Referring to the reduced copy of Sheet III, Exercise II, draw one view of the T, placing it so that the two axes are parallel to the plane of projection. The line defining the upper surface of the cylinder A, Fig. 27, may be drawn $\frac{1}{2}$ inch from the upper border line and $1\frac{1}{4}$ inches from the left border line. Draw an end view of both cylinders, locating their centers at any convenient distance, say $\frac{3}{4}$ inch, from the lower end of the long cylinder and the free end of the short cylinder. Divide the circumference of the end views into any convenient number of equal parts, say twelve, and from the points of division project the elements. Since the ends of the cylinders are at right angles to their axes, the lines defining them in the horizontal view can be used as girth lines.

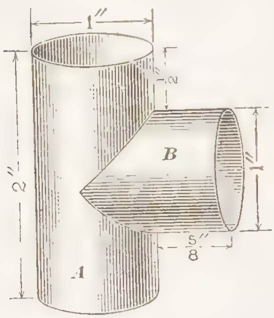


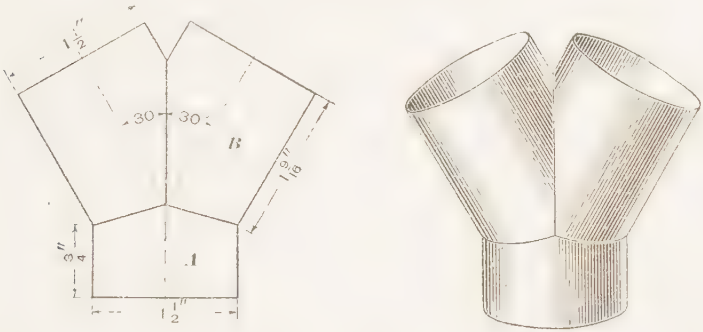
Fig. 27

To develop the long cylinder A, draw the stretchout line $a\,b$ and on it lay out the stretchout, locating it $\frac{1}{2}$ inch from the lower border line and $\frac{1}{2}$ inch from the left border line. Divide the stretchout into twelve equal parts and draw the edge lines, laying off on them the lengths of the corresponding elements. On the edge lines *4–4* to *10–10*, inclusive, lay off the points *4–4′*, *5–3′*, *5–5′*, etc., making their distances from the stretchout line equal to *4–4′*, *5–3′*, *5–5′*, etc. of the horizontal view. Using an irregular curve, join the points *1′*, *2′*, *3′*, etc. The four outer edges of the pattern, obviously, will form a rectangle.

To develop the short cylinder B, draw the stretchout line $c\,d$ in any convenient position, say $2\frac{7}{8}$ inches from the lower border line, and on it lay off the stretchout *1–1*, at a distance of $\frac{1}{2}$ inch from the left border line. Divide the stretchout to suit the division of the end view of the cylinder B; draw the edge lines, and take the lengths of the elements from the horizontal view, transferring their lengths to the

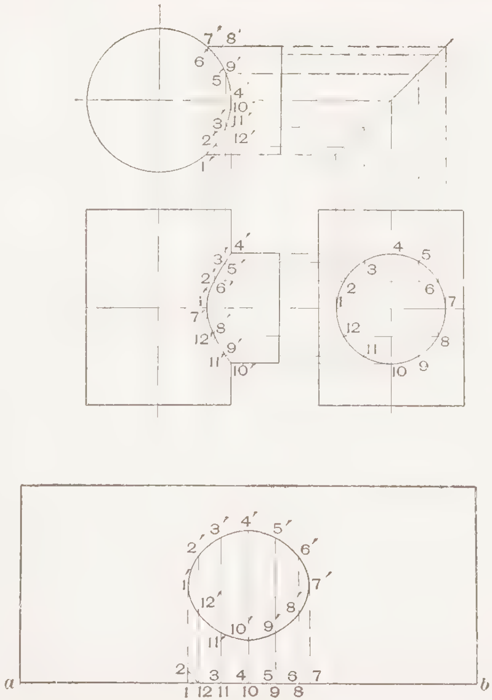
corresponding edge lines. Since the free end of the cylinder *B* is at right angles to its axis, no girth line need be drawn, as all measurements can be made from the line defining the free end.

Instead of drawing an end view of the cylinder *B* and dividing the end view for the purpose of obtaining the position of the elements on that cylinder, the elements can be drawn from the points of intersection *2′*, *3′*, *4′*, etc. on the miter line. This method is theoretically exact, and hence it is a question of individual preference whether to adopt it or the method shown in the solution of Problem 11.

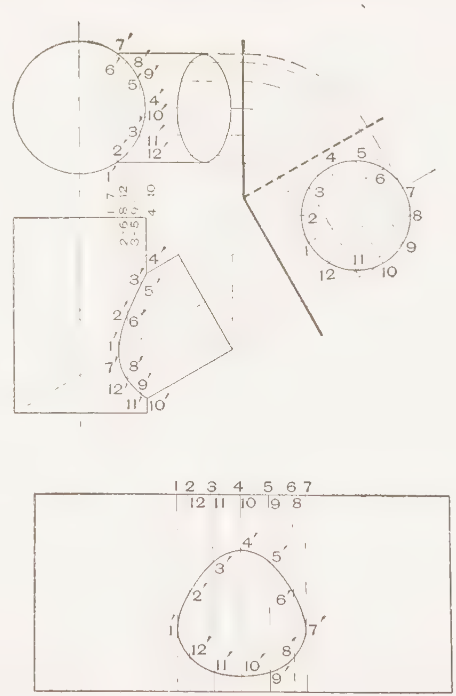


(*a*) Fig. 28 (*b*)

Problem 12.—Develop the two patterns for the **Y** shown in orthographic projection in Fig. 28 (*a*) and in perspective in Fig. 28 (*b*). This consists of three cylinders of equal diameter whose axes intersect in the same point, the free ends of the cylinders being at right angles to their axes. Draw a view of the cylinders so that the three axes shall be parallel to the plane of projection, locating the center line of the cylinder *A* $1\frac{13}{16}$ inches from the upper border line and making it parallel thereto; the free end of the cylinder *A* may be located $4\frac{5}{16}$ inches from the right border line. Locate the stretchout for the cylinder *A* $2\frac{7}{8}$ inches from the lower border line, drawing it parallel thereto. The stretchout for the cylinder *B* may be located $\frac{1}{2}$ inch from, and parallel to, the lower border line. Both stretchouts may be at a distance of $\frac{5}{8}$ inch from the right border line.



Problem 13



Problem 14

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EXERCISE III

26. In the development of the surfaces of intersecting cylinders of unequal diameter, no new principles are encountered; the miter line, however, is not a straight line, as in the case of cylinders of equal diameter drawn with their axes parallel to the plane of projection, and hence must be very carefully projected point by point in accordance with the principles of projection.

PROBLEM 13. Sheet I.—The axes of the two cylinders shown in orthographic projection in Fig. 29 intersect at right angles; the free ends of the cylinders are at right angles to their curved surface. Develop the pattern for the large cylinder.

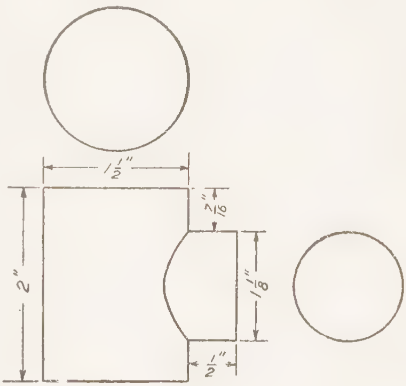
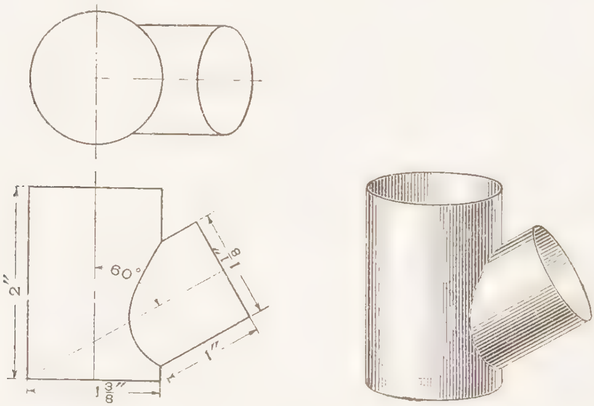


FIG. 29

SOLUTION.—Referring to the reduced copy of Sheet I, Exercise III, draw three views of the intersecting cylinders. In the solution shown the cylinders are placed inside of the planes of projection so that their axes are parallel to the front plane, and the axis of the large cylinder is perpendicular to the horizontal plane; the cylinders may, however, be placed in any other convenient position in which the elements used for finding the miter line will show in their true length. The center of the top view of the large cylinder may be located $1\frac{1}{4}$ inches from the upper border line and 2 inches from the left border line; in the front view, the center line of the small cylinder may be located $3\frac{3}{8}$ inches from the upper border line. In the side view, the center line of the large cylinder may be located $4\frac{7}{16}$ inches from the left border line.

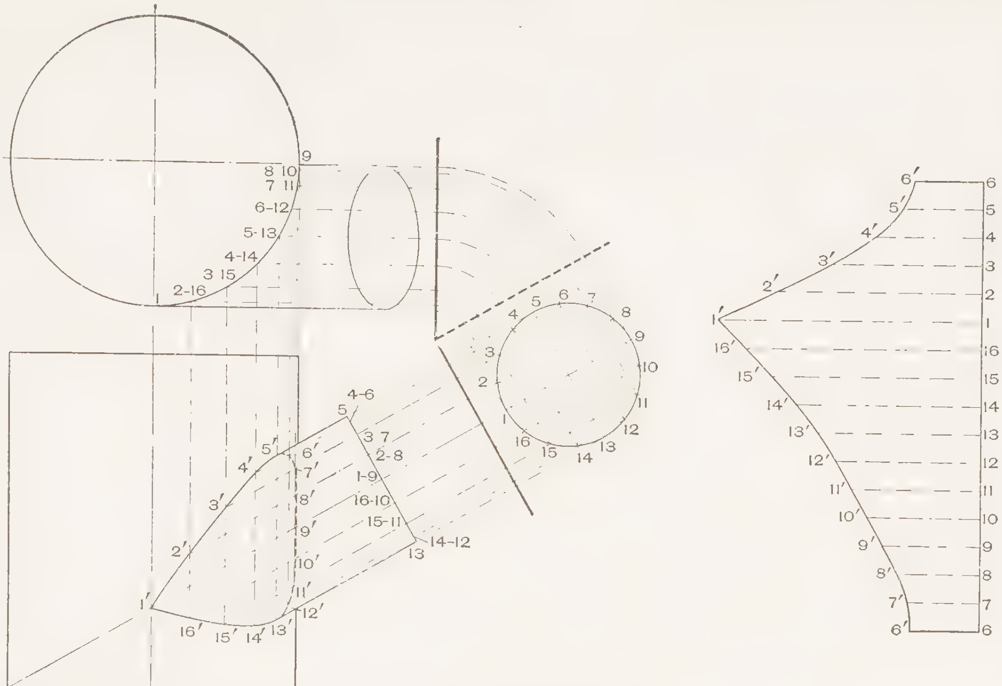
The outer circumference of the pattern is, obviously, a rectangle having a height equal to the height of the large

cylinder, and a width equal to its circumference. Draw this rectangle about $\frac{5}{8}$ inch from the left border line and $\frac{3}{4}$ inch from the lower border line. Since the ends of the large cylinder are at right angles to its axis, no girth line needs to be drawn, as all measurements for the hole in the pattern can be made from either the upper or the lower line denoting the end surfaces in the front view. Suppose that the lower line is choosen and that, for the sake of convenience, the same elements are used for the pattern that were used for determining the miter line. In any convenient location on the stretchout *a b*, corresponding to the edge of the lower end of the cylinder, lay off the distance *1–7* equal to the length



(*a*) Fig. 30 (*b*)

of the arc *1′–7′* of the top view. As inspection shows the arc to be more than one-sixth of the circumference, it is advisable to divide it into several parts, finding the length of each part by the graphical method given in *Geometrical Drawing* for finding a straight line equal in length to a given arc. The overall distance *1–7* having been laid off on *a b*, lay off the distance *1–2*, *2–3*, etc. equal to *1′–2′*, *2′–3′*, etc. of the top view. Through the points *1*, *2*, *3*, etc. on *a b* draw edge lines and lay off on these the distances *1–1′*, *2–2′*, etc. equal to *1–1′*, *2–2′*, etc. of the front view. Through the points *1′*, *2′*, etc. of the pattern draw the outline of the hole, using an irregular curve.



Problem 15

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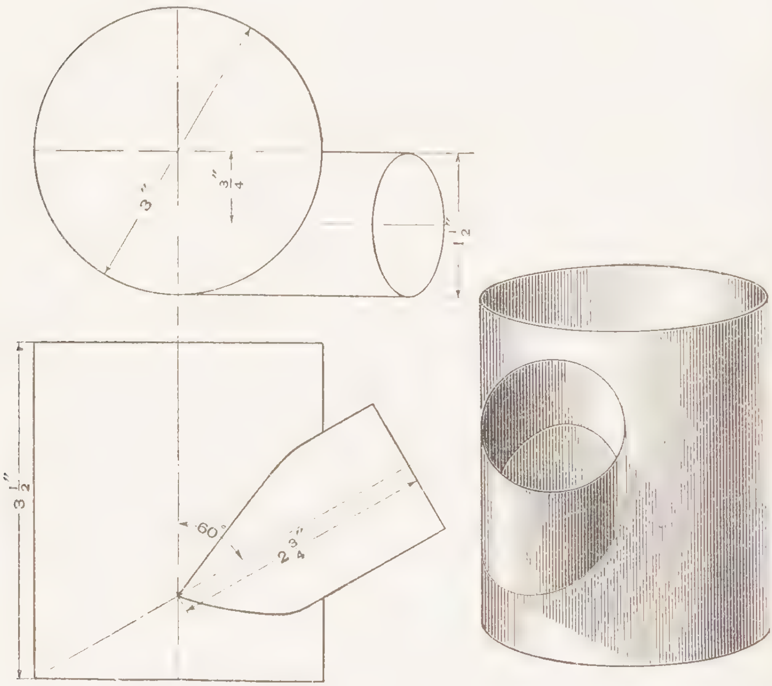
PROBLEM 14.—The two cylinders shown in orthographic projection in Fig. 30 (*a*) and in perspective in Fig. 30 (*b*) intersect in such a manner that the axis of the small cylinder intersects both the axis and the circumference of the base of the large cylinder, and makes an angle of 60° with the axis of the large cylinder. The free ends of both cylinders are at right angles to their respective axes. Develop the pattern for the large cylinder.

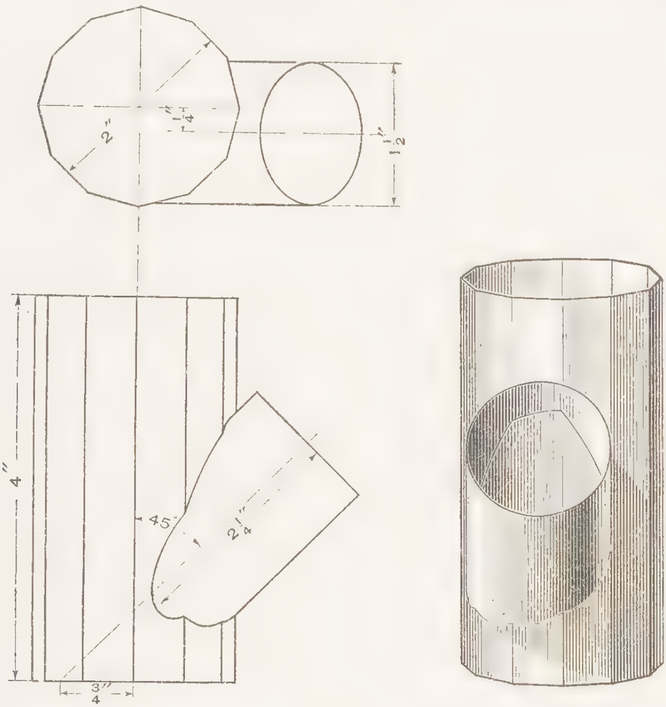


(*a*) FIG. 31 (*b*)

The center of the top view of the large cylinder may be located $1\frac{1}{4}$ inches from the upper border line and $4\frac{7}{16}$ inches from the right border line; the base of the front view may be located $3\frac{1}{8}$ inches below the center of the top view of the large cylinder. If the pattern is drawn with its long sides parallel to the lower border line, locate it $\frac{3}{4}$ inch from it and $\frac{5}{8}$ inch from the right border line.

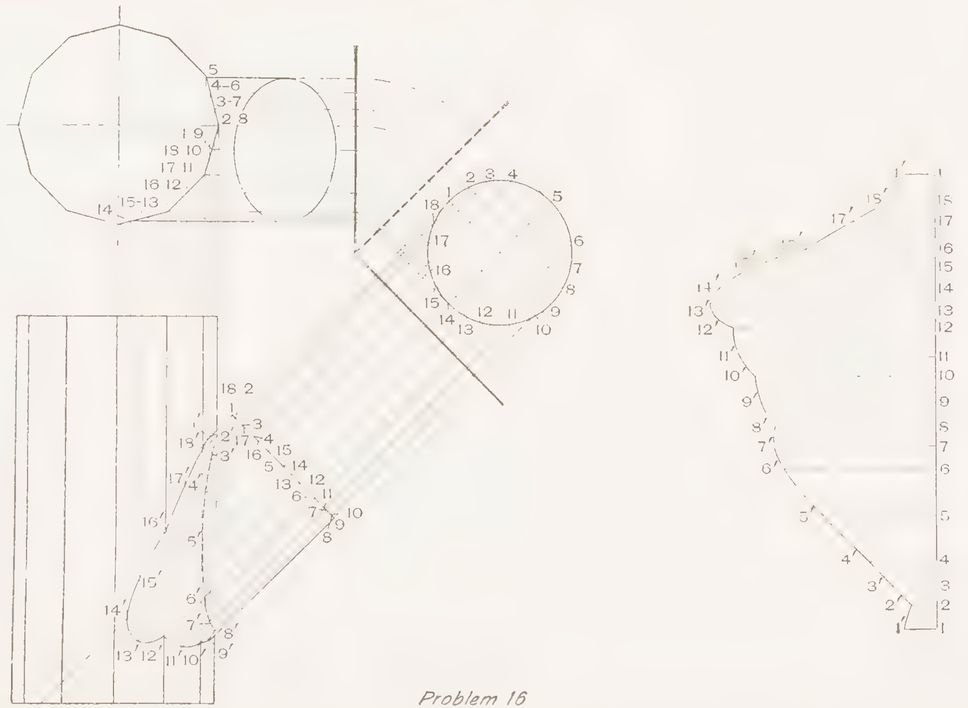
27. PROBLEM 15. Sheet II.—Develop the surface of the smaller of the two intersecting cylinders shown in orthographic projection in Fig. 31 (*a*) and in perspective in Fig. 31 (*b*).

SOLUTION.—Referring to the reduced copy of Sheet II, Exercise III, draw a top and a front view in accordance with the dimensions given in Fig. 31, locating the center of the top



(*a*) FIG. 32 (*b*)

view of the large cylinder 2 inches from the upper border line and $1\frac{3}{4}$ inches from the left border line. The line defining on the front view the base of the large cylinder may be located $\frac{1}{2}$ inch from the lower border line. Draw an end view of the small cylinder correctly located in reference to its top view; divide this end view into any convenient number of equal parts, say sixteen. From this view project elements



Problem 16

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in the front view and top view, and thus determine sixteen points of the miter line. As the free end of the small cylinder is at right angles to its axis, the length of the elements can be measured from the front projection of the free end, and no girth line need be drawn on the front view of the small cylinder.

In any convenient position, say parallel to the right border line and $\frac{5}{8}$ inch from it, draw the stretchout *6–6* equal to the circumference of the small cylinder. Divide the stretchout into sixteen equal parts; draw the edge lines, and on them lay off the length of the elements, taken from the front view, where they show in their true length. Complete the pattern by drawing a curve through the points *1′*, *2′*, etc.

28. PROBLEM 16. Sheet III.—A twelve-sided prism with the ends at right angles to its sides is intersected by a cylinder, as shown in Fig. 32. Draw the pattern for the cylinder.

Locate the center of the top view $1\frac{3}{4}$ inches from the left border line and $1\frac{1}{2}$ inches from the upper border line; the base of the front view may be located $\frac{1}{2}$ inch from the lower border line. The stretchout may be drawn parallel to the right border line and $\frac{3}{4}$ inch from it.

For finding the miter line, elements should be located so they intersect edges of the prism, and such additional elements as may be dictated by judgment should be located between these.

DEVELOPMENT BY RADIAL LINES

EXERCISE IV

29. As previously stated, the second general division of solids susceptible of accurate development contains those solids that are developed on radial lines, of which the regular pyramid and cone are those most frequently met with in practice.

In the development of cylinders, elements were drawn on their curved surface and considered as edges; in other words, the cylinder was treated as a many-sided prism, this prism appearing inscribed within the cylinder. In a similar manner

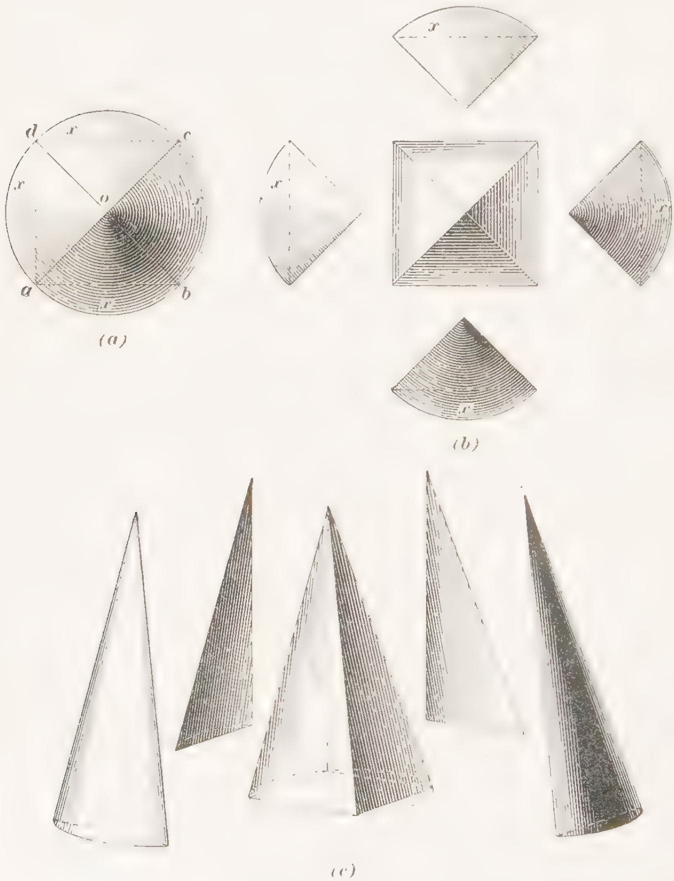


Fig. 33

it may be conceived that a many-sided pyramid is inscribed within a cone, and then its slant edges, which are also elements of the cone, used to develop the surface of the cone. This may be better understood by reference to Fig. 33 (*a*), (*b*), and (*c*).

The removal from the cone in (*a*) of the pieces marked *x*, leaves a solid that may be recognized as a quadrangular pyramid—better shown in (*b*), the pieces being removed and shown in an adjacent position. The illustration in (*c*) is a perspective drawing of the parts shown in (*a*) and (*b*), and is introduced for the purpose of showing the relation between the cone and the pyramid to better advantage. Comparing these two solids in the figure, it will be seen that the edges of the pyramid in (*b*) correspond to elements of the cone in (*a*). Further, it will be seen that, if the cone is covered with paper, as in Fig. 34, and the position of the elements noted, the paper afterwards being unrolled as shown, the elements may be imagined as leaving their imprint on the paper, as at *o a*, *o b*, etc., Fig. 34. The position of

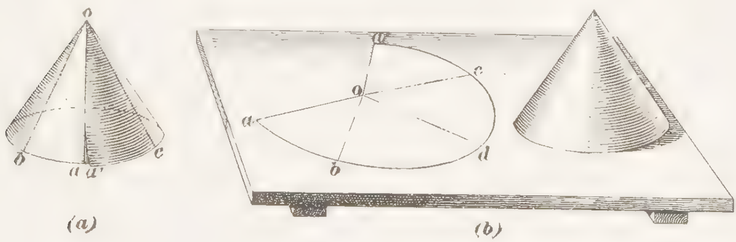
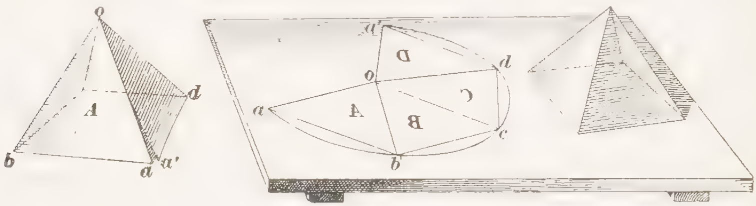


FIG. 34

these imprints will correspond relatively to the location of the elements on the surface of the solid. A figure similar to the unrolled covering may be described by the aid of the dividers, the boundaries of the development being defined by the position of any element chosen at pleasure, notice being taken of the first and last contact of such element with the drawing during a single revolution of the cone. The radius of the arc thus described is always equal to the true length of an element, and the length of the arc is equal to the circumference of the base of the cone.

Suppose, now, that the surface of the pyramid shown in Fig. 33 (*b*) is covered in a similar manner, the covering being afterwards unrolled as shown in Fig. 35. It will be found that an arc described with a radius equal to that used for

the development of the cone in Fig. 34—that is, equal to the true length of an edge of the pyramid—will pass through



(a) (b)

Fig. 35

the points a, b, c, d, and a', representing the lower extremities of the upright edges of the pyramid. These points are equally distant from one another as measured on the arc.

The only difference between the developments for the two solids lies in the fact that, for the cone, the development is defined by the circular arc, while in the case of the pyramid, straight lines are drawn between the points a, b, c, etc., as shown in Fig. 35 (b).

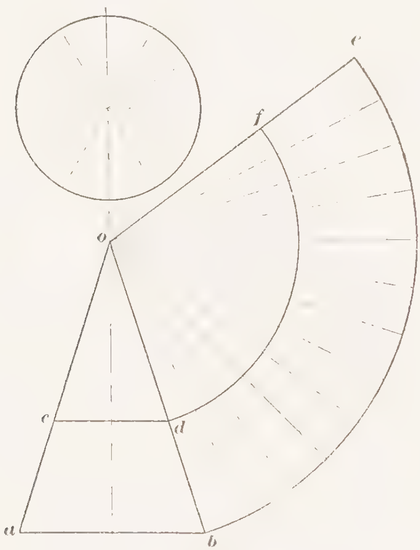


Fig. 36

30. Since the distance around the bases of the cone and the pyramid may be measured on an arc whose radius is equal to the length of one of the elements of the cone (or, in the case of the pyramid, to the length of one of its slant edges), such an arc may be described for the stretchout of these solids. The measurement around the solid being taken on a particular line, or base plane, it may here be observed that any real or assumed base plane of a

cone or pyramid may be used. The base plane must, however, always be at right angles to the center line of the cone or the pyramid. The length of the radius by which the stretchout is described must, in all cases, be equal to the true length of the elements in that portion of the solid.

This is illustrated in Fig. 36, the cone *o a b* being developed along a stretchout described with the radius *o b*. An assumed base may be taken at *c d*; an arc is then described from the center *o* with the radius *o d* (*o d* being the true length of the elements of the cone *o c d*). If the width of a space between the elements on the assumed base *c d* (measured on the plan) is taken in the dividers and spaced off on the arc *d f*, the spaces will be found to coincide with the intersection of the elements in the development drawn from the arc *b e*. The same will be found true for any right base that may be assumed for the cone. As a matter of precaution, it is customary, when drawing developments of the radial solids, to describe the stretchout with as long a radius as possible, usually not exceeding the length of the longest elements or edges shown in the drawing.

When making a development of a cone or a pyramid on the drawing board and on the same sheet of paper that contains their projection drawings, it is often very convenient to locate the center for describing the stretchout at the vertex, as was done in Fig. 36.

31. During the study of projection drawing, it was learned that measurements for all distances and the position of points on the surfaces of regular cones and pyramids, that is, radial solids, are determined by means of their radial lines, or elements. The same principle must be adhered to when developments of such solids are produced. It is essential, therefore, that these lines should be shown in their true length on drawings from which such developments are produced. This will necessitate much work, especially if the surfaces are in any way irregular or are intersected by other solids. To overcome the necessity for drawing a number of views, advantage is taken of a principle that may be observed

during the revolution of the solid. This revolution is effected in a very simple way on the drawing board, and an illustration of the method used is shown in Fig. 37. It will be understood from an inspection of that figure that if the right cone *o a b* is revolved on its axis in the direction of the arrow, the motion of any point on its surface will be indicated on the front view by a horizontal line. When any elements of the cone are in the positions occupied by the elements *o a* and *o b*, their true length is shown on the front view, and measurements may, therefore, be taken from such lines or from any points located on them. Lines in this position may be called *true edge lines*, their use under this name being peculiar to the radial solids.

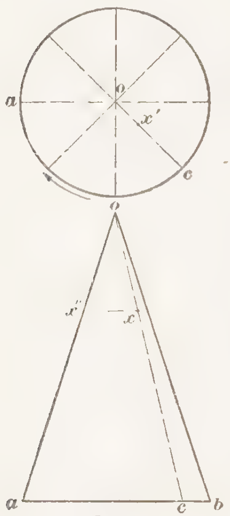


Fig. 37

When developing the surfaces of pyramids shown in certain positions, it is sometimes necessary to draw this true edge line independently of the figure. Since the elements of a regular cone are equal in length, the position of any point that may be located on any of these elements (as the point whose projections are x and x', located on the element $o\,c$, Fig. 37) may be projected in a horizontal direction to the true edge line $o\,a$ at x'', and the distance from the point o to the point x'' is then the exact, or true, distance between the two points. The point x may also be projected to the true edge line $o\,b$, if desired, to ascertain its distance from the vertex. The same result would be obtained if a projection drawing were made showing the element $o\,c$ in its true length; but, as seen from the foregoing explanation, the method here explained is much shorter.

The length of the elements of a scalene cone cannot be determined in the manner just described.

32. A summary of the rules for developing a solid by radial lines is as follows, it being understood that solids having

circular bases, or polygonal bases inscribed or circumscribed in or around a circle, with the axes passing at right angles through the center of the bases, are referred to.

1. At least two projection drawings of the solid must be made, preferably placing the solid in such a position within the planes of projection that its center line, or axis, is perpendicular to one of the planes.

2. The development is always obtained from that view in which the axis of the solid is shown in its true length (since the revolution of the solid may not readily be shown in any other view).

3. The stretchout is described with a radius equal to the length of the true edge of the solid. Sometimes its center may be conveniently located at the vertex.

4. To indicate the width and relative position of the surfaces, points are located on the stretchout corresponding to the position of those points on the outline of a sectional or base view. This view must be taken at right angles to the axis of the solid, the distance from the vertex being determined by the length of the true edge lines in the elevation.

5. Edge lines and interedge lines are always radii of the stretchout arc.

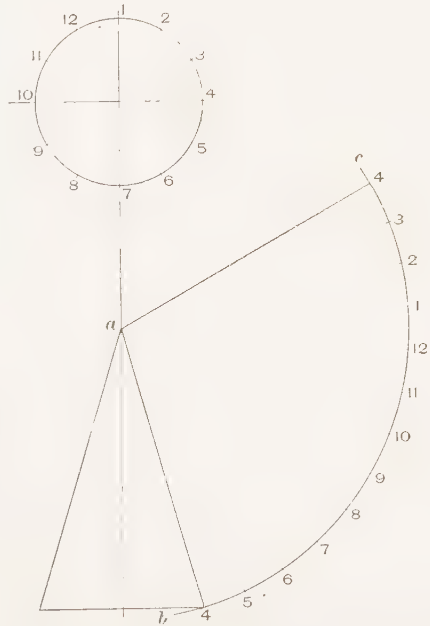
6. Points located on the surface of the solid must be projected to the true edge line by projection lines drawn at right angles to the axis.

7. In case the center of the stretchout arc is located at the vertex of the solid, developers are described with radii equal to the distances on a true edge line from the vertex to the points projected to such edge line. Each developer extends thence to its corresponding edge line or interedge line in the development.

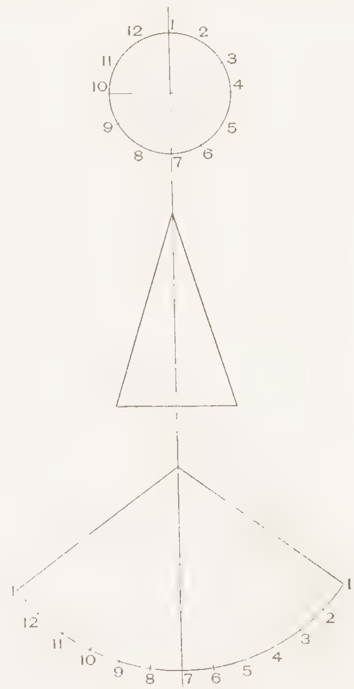
8. Interedge lines, when necessary for the development, must be indicated on the projection as well as on the development. Points located on such lines are projected to the true edge lines and thence developed in the usual manner.

9. The lengths of the outer edge lines in a complete development of a solid are equal.

Exercise IV *Development of Surfaces* *Sheet I*



Problem 17



Problem 18

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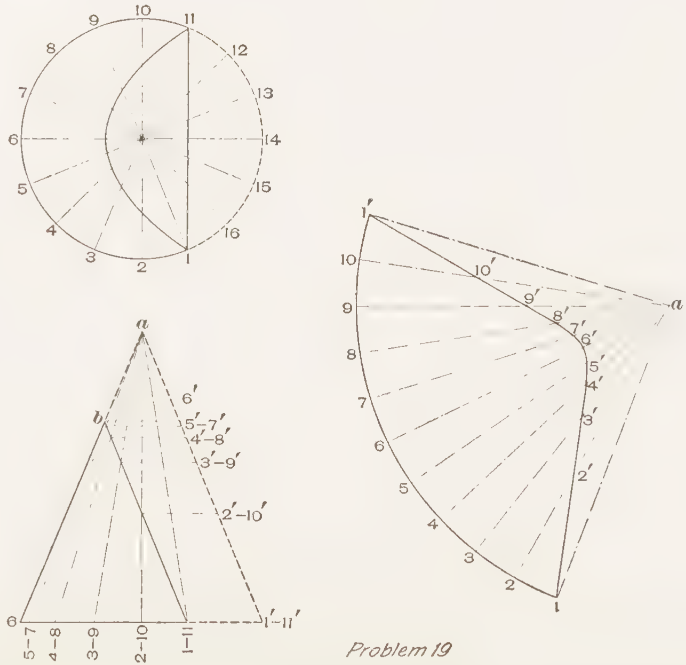
33. In the development of surfaces it often becomes necessary to lay off on the development the length of curves equal to a calculated length. This, in practice, is done in two ways, which are by means of a graduated measuring wheel or by chords. Other ways of doing this are possible, but they are too inconvenient for general use.

In practice, sheet-metal workers prefer to use the measuring wheel, which is simply a narrow wheel having a circumference of 24 inches, and graduated into inches and fractions thereof. This wheel is rolled along the curve on which a given length is to be laid off; the distance through which the wheel has been rolled is read off directly from its graduations, and when the graduation showing the desired length comes in contact with the sheet a mark is made there, a similar mark having been made at the starting point.

In laying off the length of curves by chords, the total length of the curve is divided by some convenient number, the choice of the number being purely a matter of judgment. A pair of dividers is then set to the value of the quotient, and the distance is stepped off on the curve the same number of times as the number chosen for a divisor. This method, although much used, is inaccurate and will lay off a total length slightly greater than called for.

34. PROBLEM 17. Sheet I.—Develop the surface of a right, or regular, cone whose base has a diameter of $1\frac{3}{4}$ inches and whose vertical height is $2\frac{7}{8}$ inches. The base is at right angles to the axis. Locate the center of the stretchout at the vertex of the cone.

SOLUTION.—Referring to the reduced copy of Sheet I, Exercise IV, draw a top and a front view of the cone, with the axis perpendicular to the horizontal plane. The center of the top view may be located $1\frac{3}{4}$ inches from the left border line and 2 inches from the upper border line. The vertex, in the front view, may be located $2\frac{3}{8}$ inches from the center of the top view. Divide the outline of the base in the top view into a convenient number of equal parts (in this case 12); from the vertex a of the cone as a center, describe the stretch-



Problem 19

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out arc *b c* with a radius equal to the true length of the elements of the cone, that is, the distance *a 4* in the front view. Starting at a convenient point on the stretchout, as at *4*, step off spaces equal in number and equal in length to those on the top view, thereby making the length of the stretchout equal to the circumference of the base of the cone. From each of the points thus located on the stretchout, an edge line may be drawn to the vertex *a*; but since there are no points on the surface of the cone that it is desirable to locate in this instance, only the outer edge lines *a 4*, *a 4* need be drawn to complete the pattern.

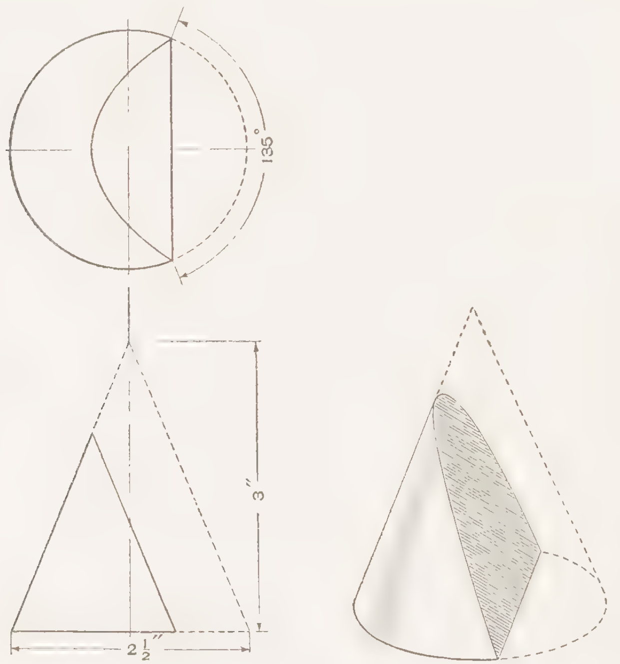
Problem 18.—Develop the surface of a right cone having a vertical height of 2 inches and a base $1\frac{1}{4}$ inches in diameter, the base being at right angles to the axis. Draw the pattern separate from the projection drawings.

The center of the top view of the cone may be located $1\frac{1}{4}$ inches from the upper border line and $2\frac{1}{2}$ inches from the right border line; the vertex of the cone, in the front view, may be located $1\frac{1}{4}$ inches from the center of the top view. The center from which the stretchout arc is described may be located $2\frac{7}{8}$ inches from the lower border line and $2\frac{1}{2}$ inches from the right border line.

35. Problem 19. Sheet II.—A right cone having a vertical height of 3 inches and a base $2\frac{1}{2}$ inches in diameter, the base being at right angles to the axis, is cut by a plane parallel to an element of the cone. This plane cuts the base in the manner shown in Fig. 38 (*a*) and (*b*). Develop the conical surface of that part of the cone shown in full lines.

Solution.—Referring to the reduced copy of Sheet II, Exercise IV, draw a top and a front view of the complete cone in accordance with the dimensions given in Fig. 38 (*a*). The center of the top view may be located $3\frac{1}{2}$ inches from the left border line and $2\frac{1}{4}$ inches from the upper border line; the front projection of the vertex may be 2 inches from the center of the top view. In the top view of the base lay off the points *1* and *11*, where the cutting plane intersects the

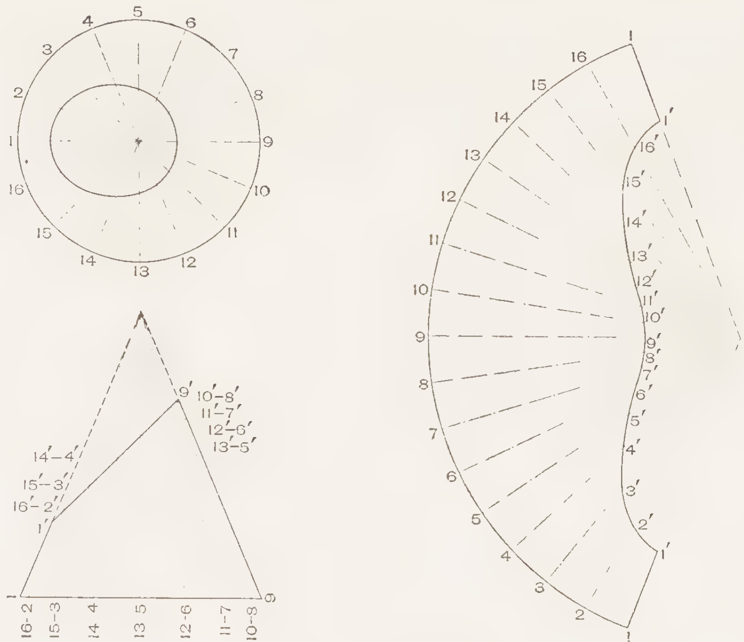
circumference, 135° apart. This is $\frac{135}{360} = \frac{3}{8}$ of the circumference. Hence, if the circumference is divided into eight equal parts, or a multiple of eight, say sixteen, parts, the points *1* and *11*, where the cutting plane intersects the circumference, are at once established. Project the points of division *1* to *16* down to the front view and draw the front view of the elements; in the front view, parallel to the element



(*a*) FIG. 38 (*b*)

a 1′, draw the line *b 1*. To get the true length of the elements, project the intersection of the elements with the front projection of the flat surface over to the element *a 1′*.

In the solution shown in the copy of Sheet II, the horizontal projection of the elements and also of the parabolic surface is drawn; however, since the development is made almost entirely from the front view, these projections may be omitted.



Problem 20

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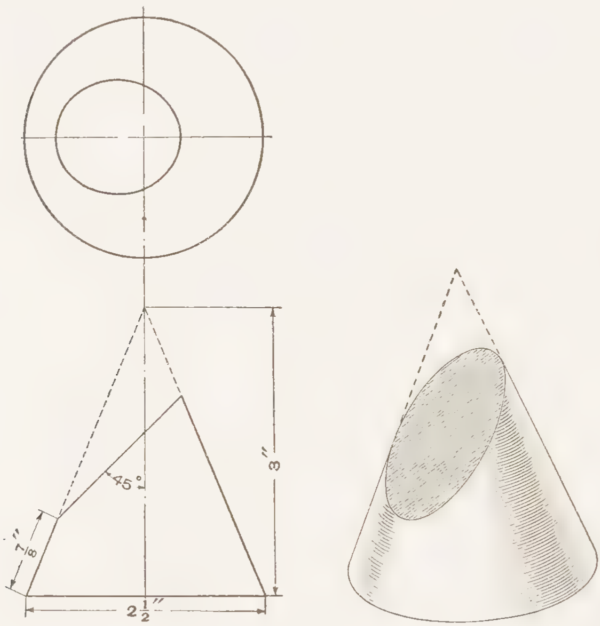
Next, with a radius equal to the element whose front projection is *a 1′*, draw the stretchout arc, locating its center about 2 inches from the right border line and 4 inches from the upper border line. On the stretchout arc lay off the distances *1–2*, *2–3*, etc. equal to *1–2*, *2–3*, etc. up to and including *10–11* of the top view. Draw the radial edge lines *a 1*, *a 2*, etc. and on them lay off the distances *a 2′*, *a 3′*, etc. equal to *a 2′*, *a 3′*, etc. of the front view.



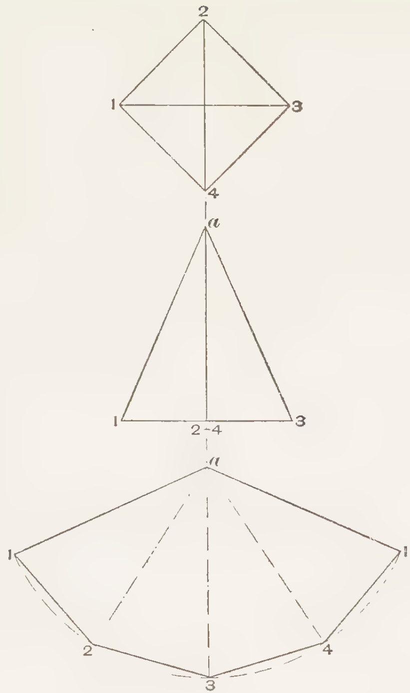
(*a*) Fig. 39 (*b*)

Through the points *1*, *2′*, *3′*, etc. of the development trace a curve, thus completing the pattern.

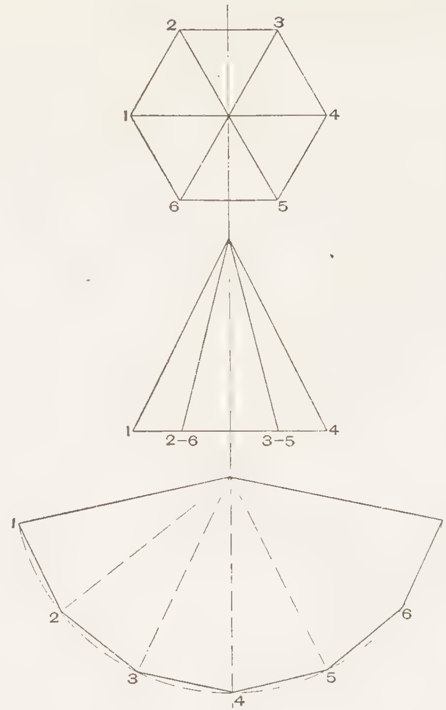
36. Problem 20. Sheet III.—Develop the curved surface of the frustum of the cone shown in orthographic projection in Fig. 39 (*a*) and in perspective in Fig. 39 (*b*).

Locate the center of the top view 2 inches from the upper border line and 3 inches from the left border line; the front projection of the vertex may be located $1\frac{3}{4}$ inches from its

Exercise V *Development of Surfaces* *Sheet I*



Problem 21



Problem 22

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horizontal projection. The center of the stretchout arc may be 4 inches from the upper border line and $1\frac{3}{4}$ inches from the right border line.

EXERCISE V

37. In the development of pyramids great care must be exercised to observe whether or not the edges in the projection drawings show in their true length. In the case of regular pyramids, with all slant edges of equal length and a base at right angles to the axis, all that is required is that one of the slant edges be in a plane parallel to one of the planes of projection; likewise, the base should be in a plane parallel to one of the planes of projection.

When the slant edges of a pyramid are of unequal length, great care must be exercised to find their true length before attempting to lay out the pattern, either by revolving the surface bounded by each pair and a base edge until it is parallel to a plane of projection, or by using the method of constructing a right-angled triangle from the two given projections of each edge, or by revolving the edges separately into a plane parallel to a plane of projection.

38. Problem 21. Sheet I.—A pyramid has a square base with sides $1\frac{1}{4}$ inches long, the base being at right angles to the axis. The vertical height of the pyramid is 2 inches. Develop the surface of the four sides.

Solution.—Referring to the reduced copy of Sheet I, Exercise V, draw a top and a front view of the pyramid in such a way that two of the inclined edges are parallel to the front plane, and the sides of the base are parallel to the horizontal plane, and hence show in their true length. The center of the horizontal view may be $1\frac{1}{4}$ inches from the upper border line and $2\frac{1}{2}$ inches from the left border line, and the front projection of the vertex may be $1\frac{1}{4}$ inches from its horizontal projection. Next, with a center about $2\frac{1}{2}$ inches from the left border line and 3 inches from the lower border line, and a radius equal to the front projection *a 1* of an edge, draw the stretchout arc and on it step off the lengths *1–2*,

2–3, etc. of the sides of the base, taken from the horizontal view. On the pattern draw the edge lines *a 1*, *a 2*, etc., and the base lines *1–2*, *2–3*, etc., thus completing it.

PROBLEM 22.—A regular hexagonal pyramid whose base has sides 1 inch long and is at right angles to the axis has a vertical height of 2 inches. Develop the pattern.

The center of the horizontal projection may be located $1\frac{1}{4}$ inches from the upper border line and $2\frac{3}{4}$ inches from the right border line; the front projection of the vertex may be $1\frac{1}{4}$ inches from its horizontal projection, if the projection

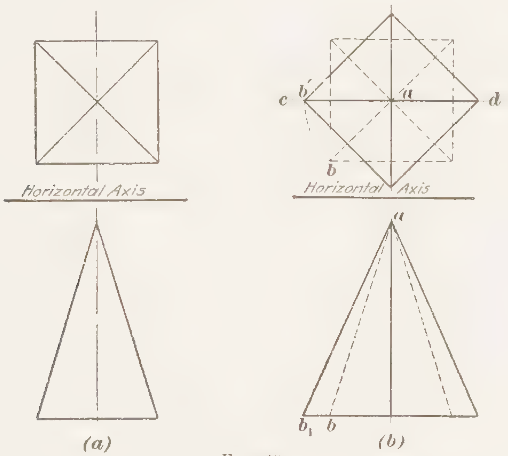
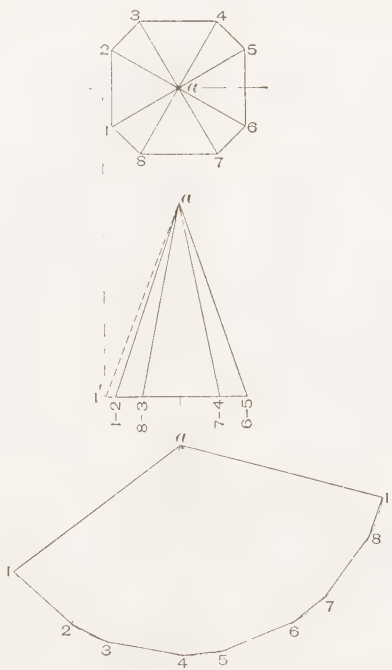


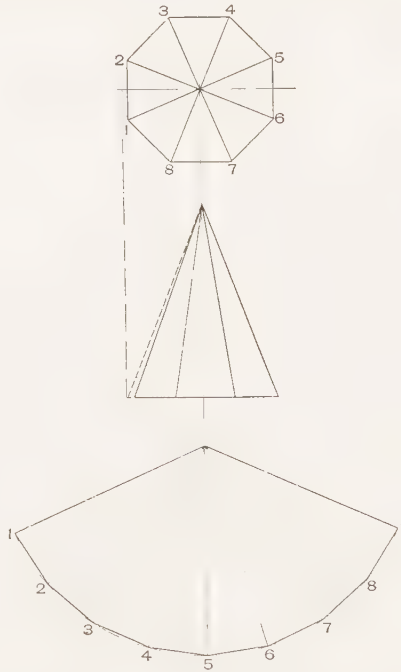
FIG. 40

drawings are made with the axis of the pyramid perpendicular to the horizontal plane and with the vertex nearest to that plane. The center of the stretchout arc may be located $2\frac{3}{4}$ inches from the right border line and 3 inches from the lower border line.

39. In making projection drawings of regular pyramids with inclined edges of equal length, it is not always convenient (although it is possible to do so) to draw the views so that one of the equal edges shows in its true length. In such a case it is very convenient to use an adaptation of the method explained in Art. **31** for the development of regular cones.



Problem 23



Problem 24

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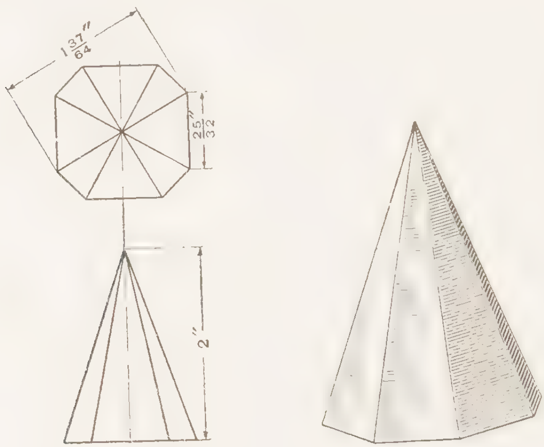
In Fig. 40 (*a*) are shown the horizontal and front projections of a square-based pyramid in which none of the inclined edges show in their true length, because none is in a plane parallel to one of the planes of projection. Now, as shown in Fig. 40 (*b*), rotate the pyramid around its axis from the original position shown in dotted lines until the edge $a\,b$ is in a plane passing through the axis of the pyramid and parallel to the front plane, this auxiliary plane being shown by its horizontal trace $c\,d$. Then $a\,b'$ becomes the horizontal projection of the edge $a\,b$, and $a\,b_1$ the front projection of the same edge, shown in its true length.

In practice, it is entirely unnecessary to redraw both views; in the case under discussion, in the horizontal view, with a as a center and $a\,b$ as a radius, describe an arc intersecting the horizontal trace $c\,d$ in b'. Project the point b' into the front plane. The front projection of the point b, owing to the axis of the pyramid being perpendicular to the horizontal plane, during the revolution of the pyramid moves in a plane parallel to the horizontal plane; the front trace of that plane is parallel to the horizontal axis. Then through the front projection of the point b draw a line parallel to the horizontal axis, intersecting at b_1 the projection line drawn from b'.

Instead of finding the true length of an edge directly on the views of the pyramid in the manner described in Art. **38,** a right-angled triangle may be constructed in any convenient position. In this triangle one of the sides adjacent to the right angle will have a length equal to that of one projection of the edge, and the other side adjacent to the right angle will have a length equal to the perpendicular height of the second projection of the edge; in other words, the true length is found by triangulation.

40. PROBLEM 23. Sheet 11.—In the octagonal pyramid shown in orthographic projection in Fig. 41 (*a*) and in perspective in Fig. 41 (*b*) alternate sides are equal, and the base is inscribed in a circle $1\frac{37}{64}$ inches in diameter. The base is at right angles to the axis. Develop the pattern.

Solution.—Referring to the reduced copy of Sheet II, Exercise V, draw the top and the front view in accordance with Fig. 41, locating the center of the top view 3 inches from the left border line and 1 inch from the upper border line. The front projection of the vertex may be located $1\frac{3}{16}$ inches from the center of the top view. Although all slant edges are equal, none shows in its true length. Hence, by the method given in Art. **38,** or, if preferred, by that given in Art. **39,** determine the true length *a 1′* of one of the edges, say *a 1*. With the center *a* of the stretchout arc in any convenient position, say 3 inches from the left border



(*a*) Fig. 41 (*b*)

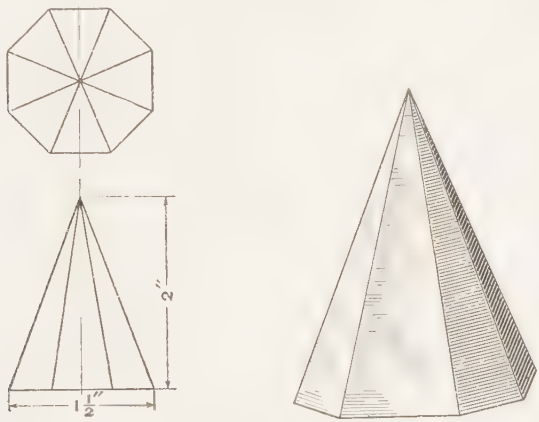
line and $3\frac{1}{4}$ inches from the lower border line, and a radius equal to *a 1′* of the front projection, draw the stretchout arc, and on it lay off the lengths *1–2*, *2–3*, etc. of the sides of the base, taken from the horizontal view. On the pattern draw the base lines *1–2*, *2–3*, etc., and the radial edge lines *a 1*, *a 2*, etc., thus completing it.

Problem 24.—Develop the surface of the octagonal pyramid shown in Fig. 42 (*a*) and (*b*). The eight sides are equal, and the base is at right angles to the axis.

The top view may either be drawn as in Fig. 42, or so that two edges show in the front view in their true length.

The horizontal projection of the vertex may be located 1 inch from the upper border line and 3 inches from the right border line; the front projection of the vertex may be located $1\frac{3}{16}$ inches from its horizontal projection. The center of the stretchout arc may be located 3 inches from the right border line and $3\frac{1}{4}$ inches from the lower border line.

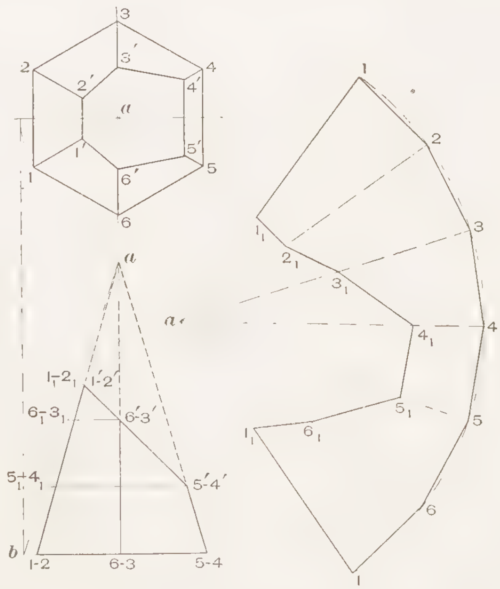
41. When a pattern is to be developed for a frustum of a pyramid, in which frustum one or both ends are not at right angles to the axis of the pyramid, it is to be noted that in the projection drawings a number of the edges will be foreshortened, and hence their true length must be determined



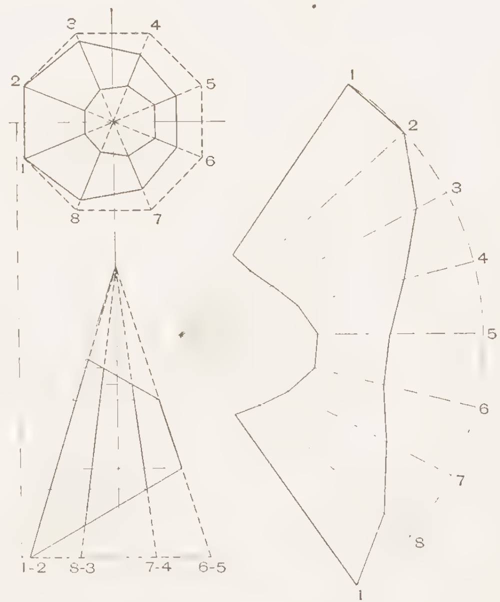
(a) FIG. 42 (b)

first of all. When the frustum is cut from a regular pyramid, that is, a pyramid having slant edges of equal length and a base at right angles to the axis, the true length of each slant edge of the frustum, and the true distance from the vertex, can be found by projecting to a true edge line, as described in Art. **31.** When the frustum is drawn so that no edge shows in its true length, a true edge line is first determined in the manner described in Art. **39,** that is, by rotation.

When a pyramid from which a frustum is cut is irregular, that is, if its slant edges are unequal in length and it has no equal-sided base, it is customary, in practice, to develop the surface of the frustum by triangulation.



Problem 25



Problem 26

Date

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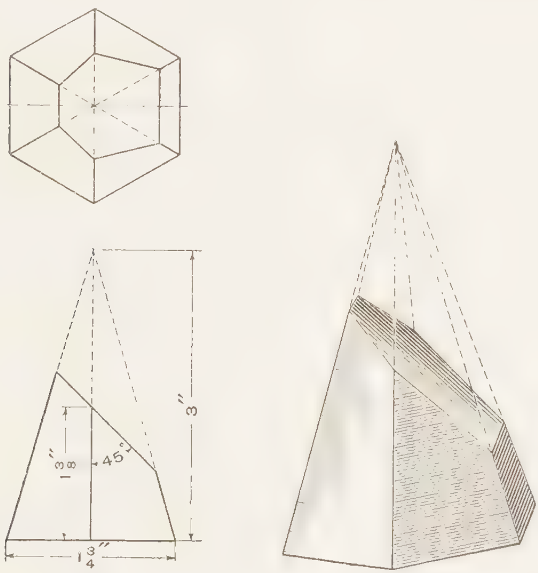
42. Problem 25. Sheet III.—Develop the pattern for the frustum of the regular pyramid shown in Fig. 43 (*a*) and (*b*).

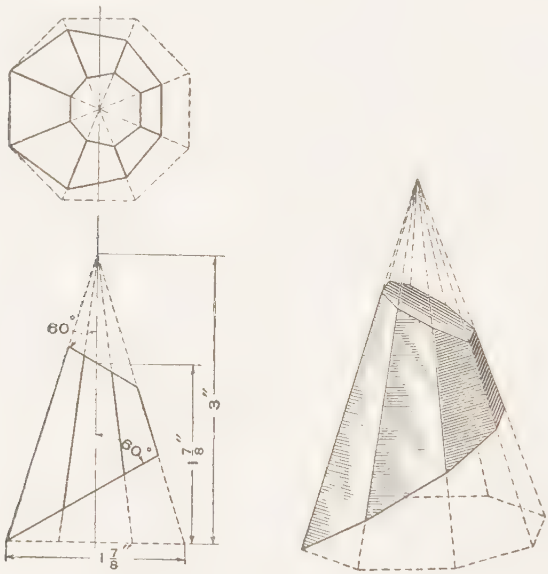
Solution.—Referring to the reduced copy of Sheet III, Exercise V, draw the horizontal and the front view in accordance with the dimensions given in Fig. 43. The center of the top view may be located $1\frac{3}{4}$ inches from the upper border line and $1\frac{5}{8}$ inches from the left border line; the front pro-



(*a*) Fig. 43 (*b*)

jection of the vertex may be located $1\frac{1}{2}$ inches from its horizontal projection. Examination of Fig. 43 shows that all slant edges of the pyramid whose frustum is to be developed are of equal length; consequently, it is sufficient to find the true length of but one of them, say *a 1*. This may be done by the method described in Art. **39.** To find the true length of the edges *1–1′*, *2–2′*, etc. of the frustum, project the ends *1′*, *2′*, etc. to the true edge line *a b*, when $b\ 1_1$, $b\ 2_1$, etc. will be the true length of the edges *1–1′*, *2–2′*, etc.

With a center a located about $3\frac{7}{8}$ inches from the upper border line and $2\frac{1}{4}$ inches from the left border line, and a radius equal to the true edge line $a\,b$, describe the stretchout arc and on it step off in succession the lengths of the base edges *1–2*, *2–3*, etc., taken from the top view, where they show in their true length, since the base was drawn parallel to the horizontal plane. On the pattern draw the base lines *1–2*, *2–3*, etc., and the radial edge lines $a\,1$, $a\,2$, etc. On the radial edge lines lay off from the center a the distances $a\,1_1$,

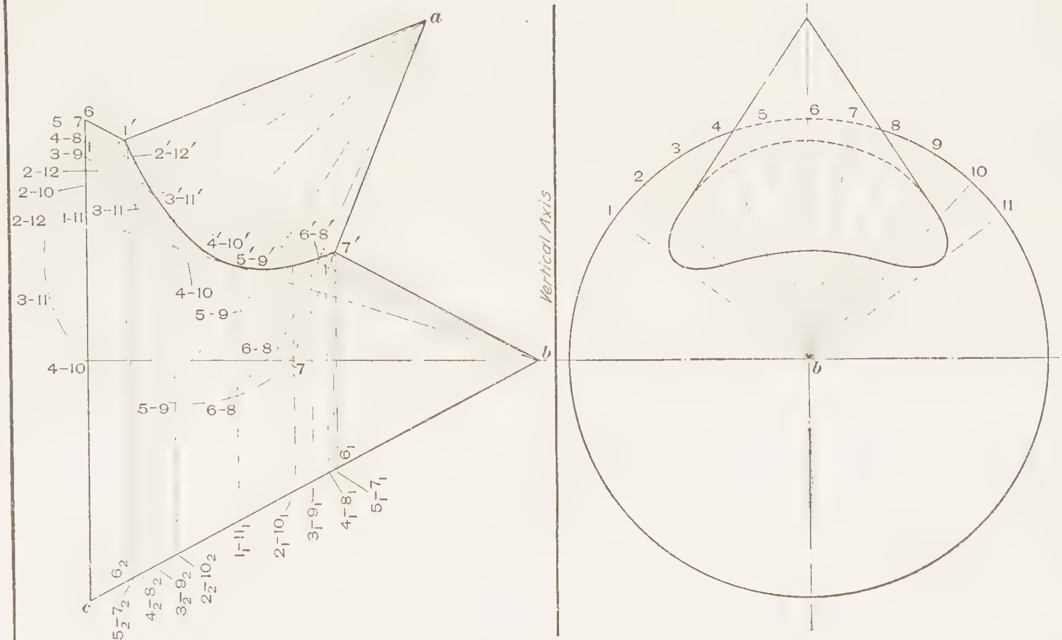


(*a*) FIG. 44 (*b*)

$a\,2_1$, etc. equal to $a\,1_1$, $a\,2_1$, etc. of the front projection; or, what is the same thing, lay off $1–1_1$, $2–2_1$, etc. equal to $b\,1_1$, $b\,2_1$, etc. On the pattern, draw the straight lines $1_1–2_1$, $2_1–3_1$, etc., thus completing it.

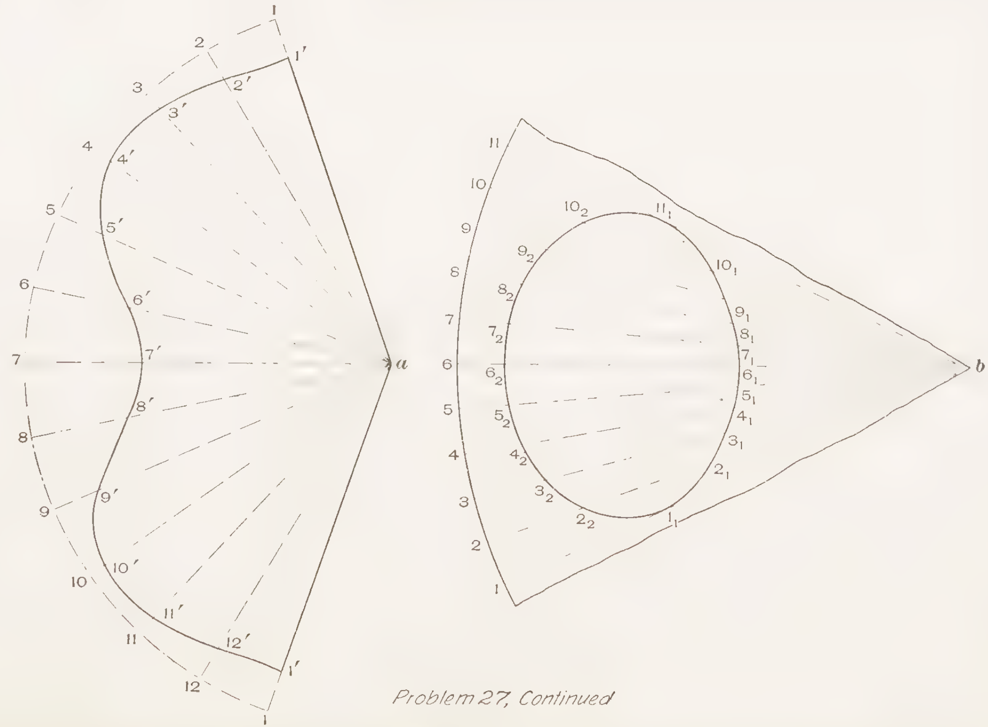
PROBLEM 26.—Develop the frustum of the pyramid shown in Fig. 44 (*a*) and (*b*).

Locate the horizontal projection of the vertex $1\frac{3}{4}$ inches from the upper border line and $4\frac{1}{8}$ inches from the right border line; locate the front projection of the vertex $1\frac{1}{2}$ inches



Problem 27

Date Name of Student, Class Letters, and Number



Problem 27, Continued

Date *Name of Student, Class Letters, and Number*

from its horizontal projection. The center of the stretchout arc may be located 4 inches from the upper border line and $3\frac{1}{2}$ inches from the right border line.

EXERCISE VI

43. No new principles are encountered in the development of the surfaces of intersecting radial solids. The great-

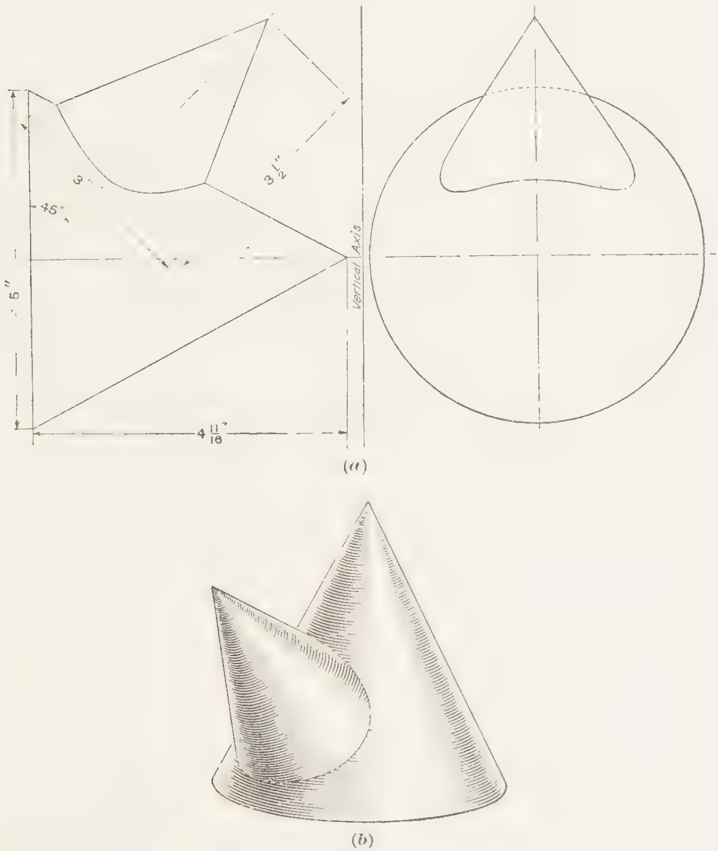


Fig. 45

est of care, however, is necessary to draw correctly the projections of the miter line on the several projection drawings

from which the developments are made, and to find the true length of all elements used for development, which are foreshortened. As a general rule, the elements used for finding the miter line can also be used to advantage for the development, thereby doing away with unnecessary multiplication of lines on the projection drawings.

Problem 27. Sheets I and II.—Develop the pattern for the smaller of the intersecting cones shown in Fig. 45 (*a*) and (*b*), and that part of the pattern for the larger cone that contains the miter line.

Solution.—Referring to the reduced copy of Sheet I, Exercise VI, draw a front and a side view of the cones in accordance with Fig. 45. The front projection of the vertex of the large cone may be located $5\frac{1}{2}$ inches from the left border line and $4\frac{1}{2}$ inches from the upper border line. The side projection of the vertex may be located $2\frac{11}{16}$ inches from the right border line. The two projections of the miter line having been carefully and accurately drawn, draw any convenient number of equally spaced elements, say twelve, on the front projection of the smaller cone. There is no need of drawing the side projections of these twelve elements.

Referring to the reduced copy of Sheet II, locate the center *a* of the stretchout arc 4 inches from the upper border line and $4\frac{1}{2}$ inches from the left border line. With the correct length *a 7*, Sheet I, of an element as a radius, describe the stretchout arc on Sheet II and on it lay off the length of the circumference of the base. Divide the stretchout into twelve equal parts and draw the radial edge lines *a 1*, *a 2*, etc. On these edge lines is to be laid off the correct distance between the vertex *a*, Sheet I, of the small cone and the miter line, on each corresponding element; in other words, the correct length of the projections *a 1′*, *a 2′*, etc. By projecting to a true edge line, find the true length of these distances and transfer them to the corresponding edge lines of Sheet II. Through the points *1′*, *2′*, etc. thus laid off draw a curve, thus completing the pattern for the small cone.

To draw the development of the miter line for the large cone, in the side view of Sheet I draw the radial lines *b 1* and *b 11* tangent to the side projection of the miter line. Divide that part of the side projection of the base that is included between the points *1* and *11* into any convenient number of equal parts, say ten, and project the points of division to the front projection of the base. Then draw the front projection *b 1*, *b 2*, etc. of the elements. Note carefully where these elements intersect the front projection of the miter line, and project these points of intersection to a true edge line, as *b c*, to obtain the true distances from the vertex *b* to the intersections of the several elements with the miter line. Referring now to Sheet II, locate the center *b* of the stretchout arc for the large cone about 4 inches from the upper border line and ½ inch from the right border line; with a radius *b c*, Sheet I, which is the slant height of the cone, describe the stretchout arc and on it lay off the distances *1–2*, *2–3*, etc., taken from the horizontal view of Sheet I. Draw the edge lines *b 1*, *b 2*, etc. and on them lay off the distances $b\ 1_1$, $b\ 2_1$, etc., and $b\ 1_2$, $b\ 2_2$, etc., taken from the front view of Sheet I. Through the points 1_1, 2_1, etc. and 2_2, 3_2, draw a curve, thus completing the pattern.

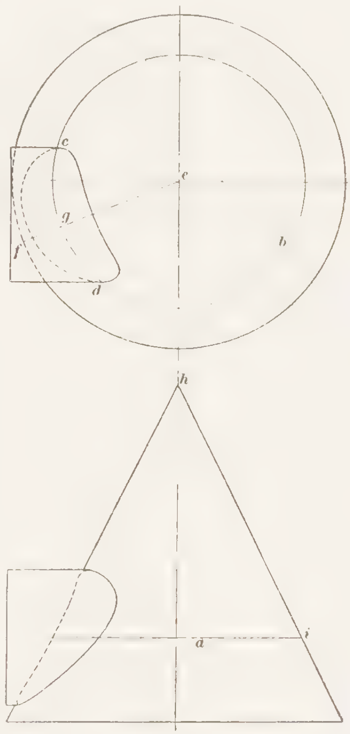


FIG. 46

44. Although, as a general rule, the development of the surface of a cone intersected by some solid is best accom-

plished by radial lines, as was done in Problem 27, cases will arise in practice in which it is very difficult to do so. These cases are those where projections of elements cross the projection of the miter line at such a small angle that the intersections of the elements with the miter line cannot be determined with any degree of accuracy.

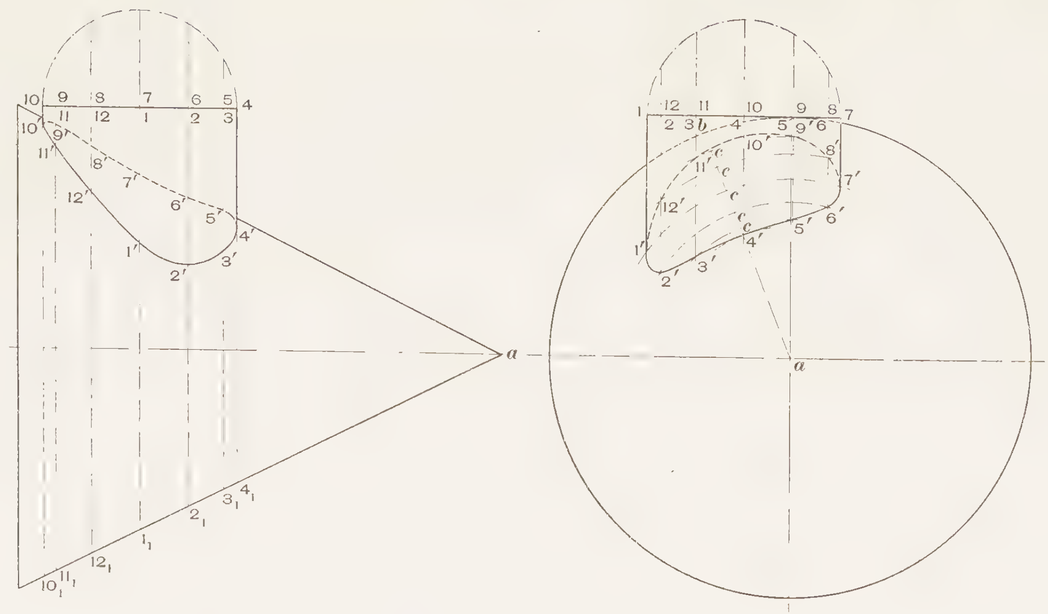
In Fig. 46 are presented two views of an intersecting cone and cylinder in which development of the miter line of the cone by elements is very difficult. The development may readily be made, however, by using the following method: Through the cone, at right angles to its axis, pass a cutting plane. The intersection of this plane with the cone is the line *a* in the front view and the circle *b* in the horizontal view. Since the circle *b* is in a plane parallel to the horizontal plane, the arc *c d* shows in its true length. In any convenient location draw the projection *e f* of an element, intersecting the arc *c d* at *g*.

To obtain the position of the points *c* and *d* of the miter line on the development, develop the circle *b*, which, on the pattern, becomes an arc having a radius *h i*. On the pattern draw an edge line corresponding to *e f*, and to both sides of its intersection with the arc having the radius *h i* lay off the length of the arcs *g c* and *g d*.

To establish more points for the development of the miter line, pass more cutting planes through the cone and proceed as just described.

45. Problem 28. Sheets III and IV.—Develop the pattern for the cylinder, and develop the miter line on the pattern for the cone, for the intersecting cylinder and cone shown in Fig. 47.

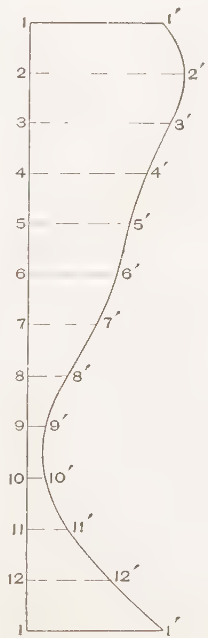
Solution.—Referring to the reduced copy of Sheet III, Exercise VI, draw the front and side views in accordance with the dimensions given in Fig. 47, using particular care to draw accurately the projections of the miter line. Locate the front projection of the vertex 4 inches from the upper border line and $5\frac{1}{4}$ inches from the left border line; locate the side projection of the vertex $2\frac{3}{4}$ inches from the right

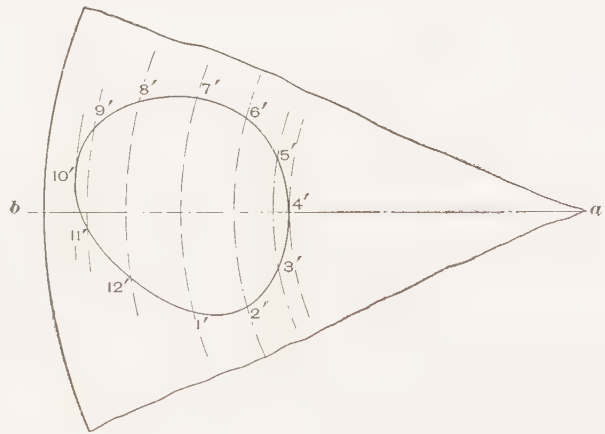


Problem 28

Date

Name of Student, Class Letters, and Number

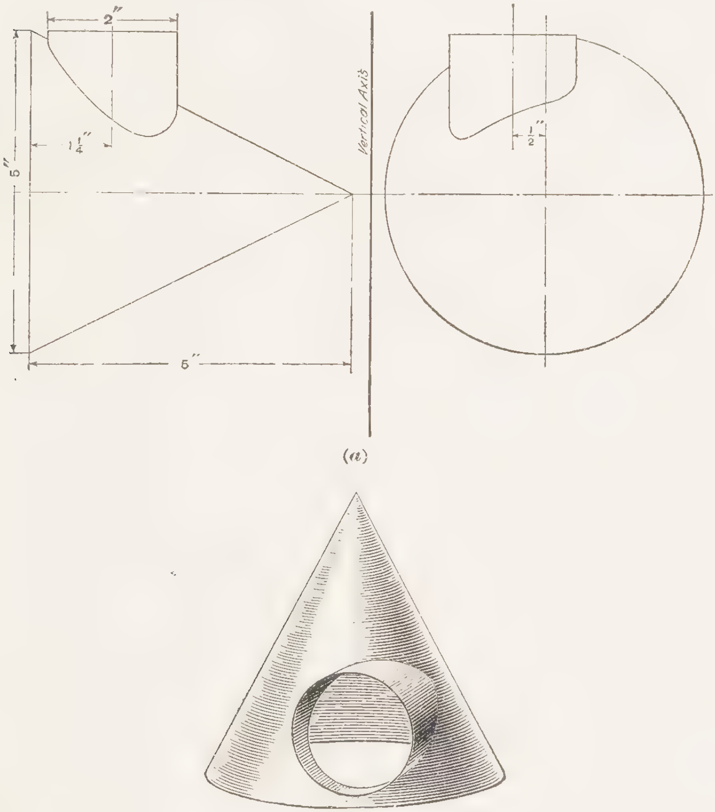




Problem 28, Continued

Date Name of Student, Class Letters, and Number

border line. Referring to the reduced copy of Sheet IV, Exercise VI, draw the stretchout for the cylinder about 1 inch from the left border line and $\frac{13}{16}$ inch from the lower border line. Develop the pattern for the cylinder by parallel lines, using any convenient number. The true length of



(a)

(b)

FIG. 47

the edge lines is given in both views, the elements in this case being parallel to both the front and the side plane.

To develop the miter line of the cone, through any convenient number of points on the miter line, say the points *1′*, *2′*, etc. on Sheet III, pass cutting planes and draw the front

and side projections of their intersections with the surface of the cone. It is not necessary to draw the complete side projection of these intersections; it is sufficient to draw arcs intersecting the side projection of the miter line. Through any convenient point of the side projection of the miter line, say the point *4′*, draw the side projection *a b* of an element.

On Sheet IV, Exercise VI, locate the center *a* of the stretch-out arc 4 inches from the upper border line and 1 inch from the right border line. With radii $a\,4_1$, $a\,3_1$, $a\,2_1$, etc., taken from Sheet III, describe arcs with the center of the stretch-out arc as a center. Draw the edge line *a b*, corresponding to the side projection of the element *a b*, Sheet III. To corresponding sides of the edge line *a b*, Sheet IV, and on the arcs, lay off the length of the arcs *c 1′*, *c 2′*, etc., taken from Sheet III. Through the points *1′*, *2′*, etc. trace a curve, thus completing the pattern.

DEVELOPMENT BY TRIANGULATION

EXERCISE VII

46. Triangulation, which is the process by which the development of solids belonging to the third general division is accomplished, is sometimes regarded as particularly intricate and difficult. It is, on the contrary, a very simple method of development, and should present no serious obstacles. This process depends for its results on two general principles: first, to find the true length of all lines, real or assumed, appearing on the surfaces of the solid; second, having determined the true length of such lines, to construct triangles similar in form and relation to those shown on the solid. The construction of a triangle whose three sides are given is a very simple problem; and the task of finding, from the projection drawings, the true lengths of its sides involves nothing but the elementary principles of that study. Having found the true lengths of the sides of such triangles as are involved in a development, nothing remains but the arrange-

ment of the triangles in their proper relation to one another on the different surfaces of the solids.

47. Although the development of surfaces by triangulation is usually applied to solids having curved surfaces, it is best illustrated by its application to a solid having plane surfaces. Such a solid is shown in Fig. 48, which gives a perspective view of what may be termed a *transition piece*—that is, a piece used to connect openings of different sizes, as in pipework. Both bases are rectangular, and, in this case, parallel, but diagonally arranged in their relation to each other, as may be seen from the figure.

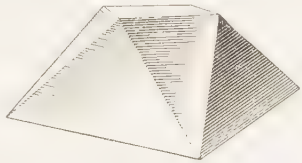


FIG. 48

It is at once seen that none of the methods described for the development of the surfaces of solids by parallel or radial lines will apply to the development of the lateral surfaces of this solid, although it is possible to project a full view of each of the surfaces shown in the figure. This, however, involves more work than is necessary, and the same result may be secured by a shorter method.

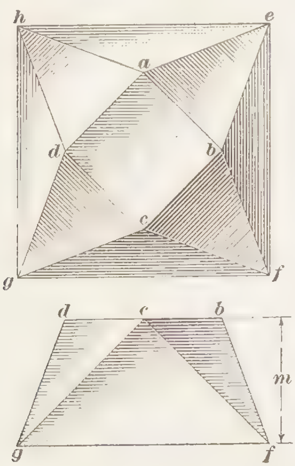


FIG. 49

Clearly, a reproduction of these triangular surfaces on the flat surface of the drawing board, in the same relative position to one another, will be a development of the solid. The only difficulty is that, in certain cases, the sides of the triangles are not shown in their true lengths. It is necessary to determine the true lengths of all lines, in order that the triangles may be constructed of the same size as they are on the surfaces of the solid.

As in most cases where a development is desired, two projection drawings must first be made. This is shown in

Fig. 49, from which it is seen that all lines of the solid that appear on either base are shown in their true length. It is therefore necessary, before the triangles may be produced, to determine the true lengths of the remaining lines of the solid. This is most readily accomplished by constructing, in each case, a right-angled triangle whose base is equal to the length of any foreshortened line in the top view, and whose altitude is equal to the vertical height of the same line, as shown in the front view. The hypotenuse of such a triangle will then be equal to the true length of the line. In this case, the lines *a h*, *d h*, *a e*, *b e*, etc., foreshortened in the top view, are all represented by lines of the same length. The vertical height *m*, Fig. 49, is the same in the case of each line.

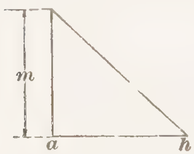


Fig. 50

A single triangle constructed by the above method, therefore, will be sufficient to indicate the true length of all lines not shown in their true length in Fig. 49. Such a triangle is constructed in Fig. 50; the base of the triangle *a h*, Fig. 50, is equal to the length of *a h*, Fig. 49, the altitude *m* being the same at *m*, Fig. 49. The hypotenuse of this triangle is therefore the true lengths of the lines *a h*, *d h*, etc. as shown in Fig. 49. The true length of all lines bordering the triangular surfaces of the solid shown in Fig. 49 having been found, the triangles may now be constructed, care being observed to complete the adjacent triangles in the same order they are shown on the solid. Any edge of the solid may be assumed as a starting place for the operation; the true length of such an edge is then laid off on a line, as *a e*, Fig. 51. The triangle *a e b*, Fig. 51, is first constructed; the length of the side *a e* having been laid off, and *b e*, Fig. 49, being of the same length, an arc may be described in Fig. 51 from *e* as a center, with a radius equal to *a e*. Intersect this arc at *b*, Fig. 51, with one described from *a* as a center, with a radius equal to *a b*, Fig. 49. Draw *a b* and *e b*, thus developing the triangle *a e b*, Fig. 51, which is the correct development of the surface *a e b*, Fig. 49.

The adjacent triangle $e\,b\,f$, Fig. 51, may next be constructed. Since $b\,f$ is equal to $b\,e$, Fig. 49, an arc may be

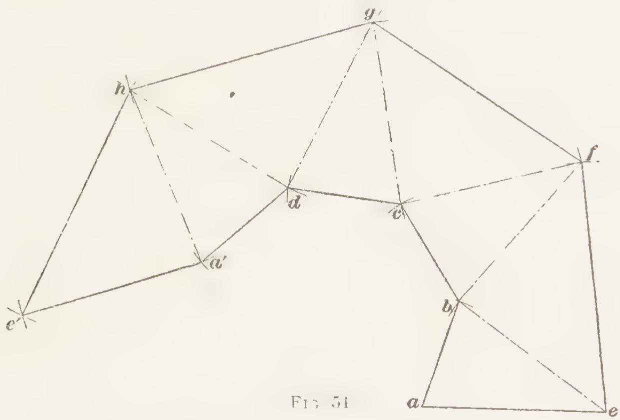


FIG. 51

described in Fig. 51 from b as a center with a radius $b\,e$; this arc is then intersected by an arc described from e as a

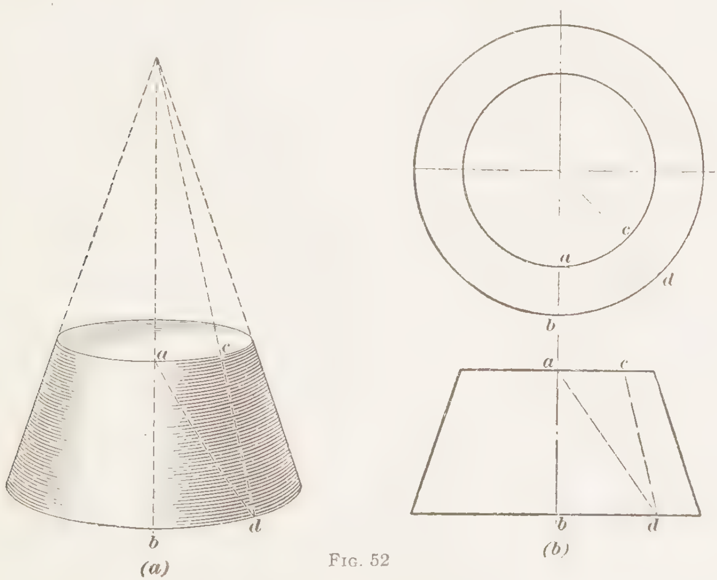


FIG. 52

center, with a radius equal to the length of $e\,f$, Fig. 49, thus developing the triangle $e\,b\,f$, Fig. 51, which corresponds to

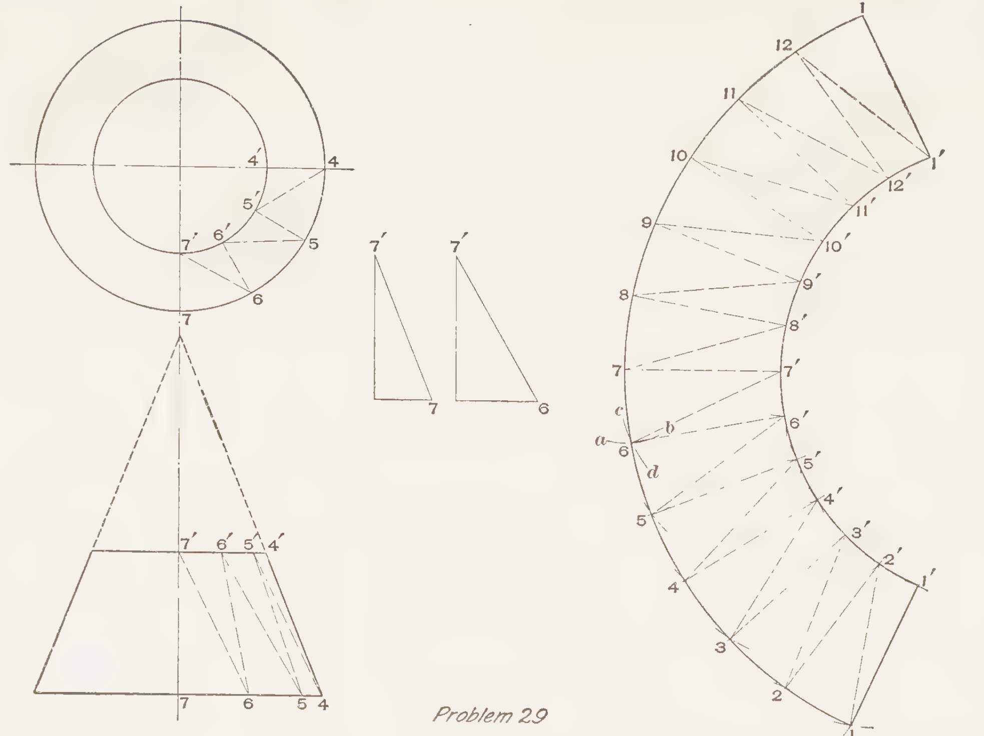
the surface *e b f*, Fig. 49. In like manner, each surface of the solid is developed, due care being observed that adjacent triangles are placed in corresponding positions in the development.

48. Except in the case of solids all of whose surfaces are planes, development by triangulation, as carried out in practice, is not mathematically correct. Some of the lines of triangles on curved surfaces are curved, and since, in triangulation, they are assumed to be straight, they are taken as slightly shorter than they are in reality. This is shown in Fig. 52, which shows in (*a*) a perspective drawing of a frustum of a regular cone, and in (*b*) two projection drawings of the same frustum. In Fig. 52 (*a*) the lines *a b* and *c d* are elements of the cone and hence are straight lines; the line *a d*, however, which is drawn on the surface of the frustum so as to be the shortest distance between the points *a* and *d*, is a curved line. In practice, the projections of the line *a d* are always drawn as straight lines, and consequently the true length of the straight line *a d*, as determined from its projections, is slightly less than the length of the curved line *a d* drawn on the solid, as in (*a*).

Although development of curved surfaces by triangulation as carried out in practice is not mathematically exact, the error is so slight and is so greatly overshadowed by unavoidable inaccuracies of workmanship that for all practical purposes the method can safely be, and is, considered as correct.

49. In practice, especially in large sheet-metal and plate work, development by triangulation is applied to many surfaces that can be developed by parallel or radial lines. The reasons for giving the preference to triangulation in such cases are of a purely practical nature, such, for instance, as that straightedges of the required size are not available; that the weight of the material is so great that it is hard to handle; or that the center of the stretchout arc in radial developments falls outside of the sheet on which the development is to be made. As a matter of fact, most sheet-metal workers use triangulation almost to the exclusion of the

Exercise VII — Development of Surfaces — Sheet I



Problem 29

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other methods, and for this reason the principles involved should be thoroughly understood.

50. PROBLEM 29. Sheet I.—Develop by triangulation the conical surface of the frustum of a cone of which two projection drawings are presented in Fig. 53.

SOLUTION.—Referring to the reduced copy of Sheet I, Exercise VII, draw the horizontal and front views, locating the center of the horizontal view $2\frac{1}{2}$ inches from the left border line and 2 inches from the upper border line. The front projection of the base may be drawn $\frac{1}{2}$ inch from the lower border line. Divide the horizontal projections of the top and base into any convenient number of equal parts, say twelve; that is, divide one quarter of the top and base into three equal parts. Project the points of division to the front view. Draw the horizontal and front projections *4–4′*, *5–5′*, etc. of the elements, and draw the horizontal and front projections *4–5′*, *5–6′*, etc. of the straight lines joining the points of division *4* and *5′*, *5* and *6′*, etc.

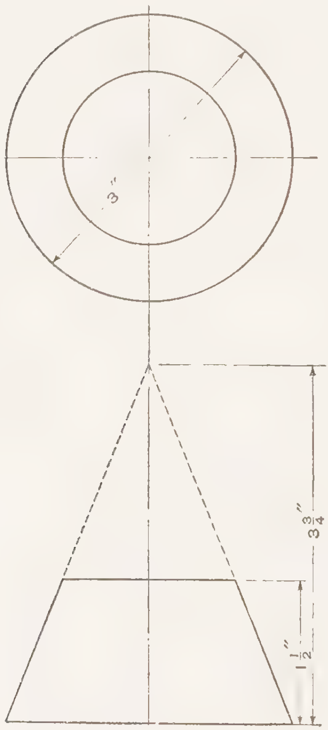
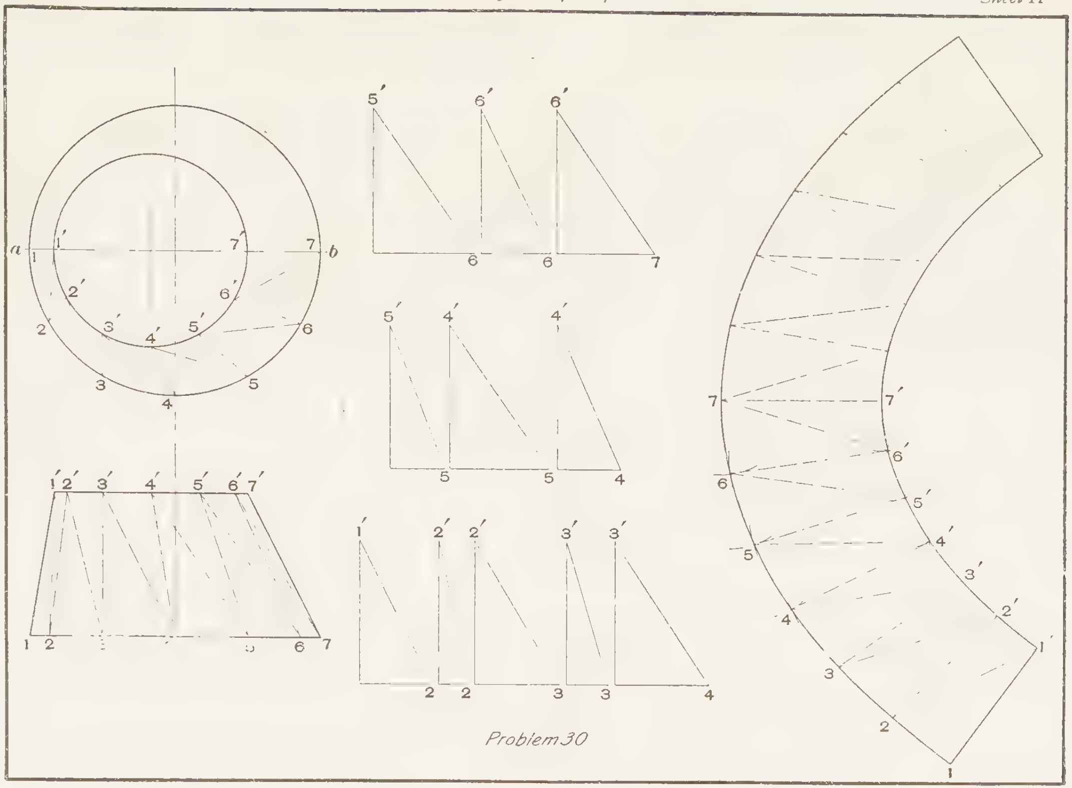


FIG. 53

Since the cone has a circular cross-section and the base and top of the frustum are at right angles to the axis, the elements *4–4′*, *5–5′*, etc. have the same length; likewise, the lines *4–5′*, *5–6′*, etc. are equal. Consequently, it is necessary to determine the true length of one element only, say *7–7′*, and of one line joining corresponding points of division, say *6–7′*. To do this, draw the two right-angled triangles shown, making their height equal to the height *7–7′* of the front pro-



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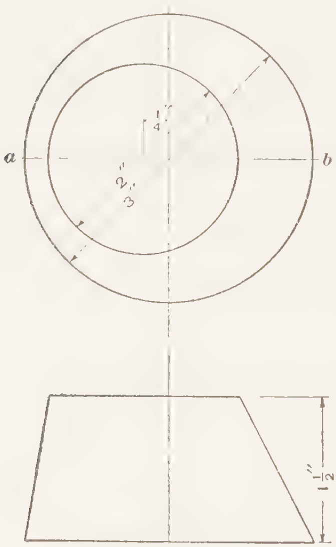
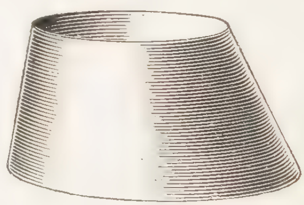
jection and their bases equal to the lengths *7–7′* and *6–7′* of the horizontal projection. The hypotenuses *7–7′* and *6–7′* are the true lengths of the corresponding projections.

Begin the laying out of the pattern by drawing a straight line parallel to the upper border line and 4 inches from it, laying off on it the true length of the element *7–7′*, locating *7′* about $2\frac{1}{4}$ inches from the right border line. With the point *7* as a center and the length of the arc *7–6* in the horizontal view as a radius, describe the arc *a b*. With the point *7′* as a center and the true length of the line *6–7′* as a radius, describe the arc *c d*. The intersection of the two arcs locates the point *6* of the pattern. With the point *6* as a center and the true length of *7–7′* as a radius, describe an arc as shown; also, with the point *7′* as a center and the length of the arc *7′–6′* as a radius, describe another arc as shown. The intersection of the two arcs locates the point *6′* of the pattern. In the same manner find the corners of the other triangles, completing the pattern by drawing the outlines through the points *1–2–3*, etc., and *1′–2′–3′*, etc., and also the straight lines *1–1′*.



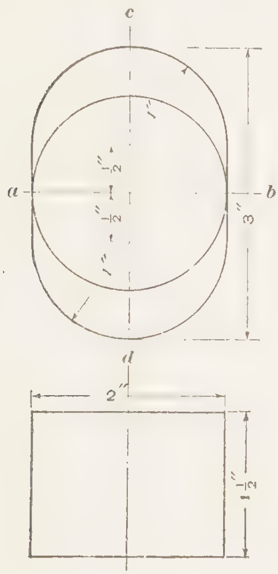


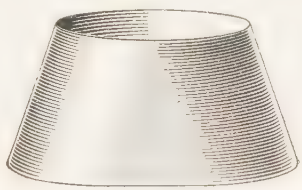
(*a*) FIG. 54 (*b*)

51. PROBLEM 30. Sheet II.—Develop the curved surface of the frustum of a scalene cone of which two projection drawings and a perspective view are shown in Fig. 54 (*a*) and (*b*).

Solution.—Referring to Sheet II, Exercise VII, draw the two projections of the frustum according to the dimensions given in Fig. 54, locating the horizontal projection of the center of the base $2\frac{1}{2}$ inches from the upper border line and $1\frac{3}{4}$ inches from the left border line. The front projection of the base may be drawn $1\frac{1}{2}$ inches from the lower border line.

Examination of the horizontal view shows that the center line $a\,b$, Fig. 54, divides the frustum into two symmetrical parts. Referring again to Sheet II, divide the horizontal projections of one-half the top and base, located on the same side of the center line $a\,b$, into the same number of equal parts, say six. Project the points of division to the front view and draw the triangles. In this case no two triangles located on one side of the center line $a\,b$ are alike. Find the true length of all the lines, noting that the lines *1–1′* and *7–7′* show in their true length in the front view, since they are parallel to the front plane.

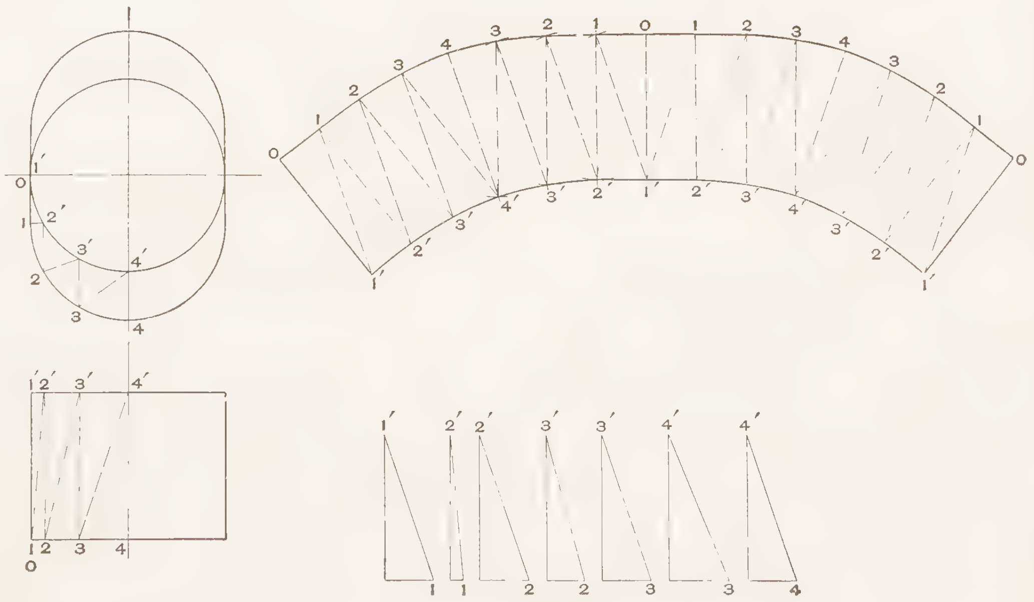




(*a*) Fig. 55 (*b*)

With the true length of the various lines, and of the arcs *1–2*, *1′–2′*, etc., which arcs are shown in their true length in the horizontal view, the pattern can now be drawn.

52. Problem 31. Sheet III.—Develop the curved surface of the transition piece of which two projection drawings and a perspective view are shown in Fig. 55 (*a*) and (*b*). Observe that the center lines $a\,b$ and $c\,d$ divide the horizontal view into four symmetrical parts.



Problem 31

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The horizontal projection of the center of the upper surface may be located $2\frac{1}{2}$ inches from the upper border line and $1\frac{1}{2}$ inches from the left border line; the front projection of the same surface may be located $2\frac{1}{4}$ inches from the horizontal projection of its center.

EXERCISE VIII

53. In the various problems of development by triangulation that have so far been presented the end surfaces of the solids developed were parallel, and consequently projection drawings of these solids could be made with the end surfaces parallel to a principal plane of projection, so that their circumferences showed on the plane in their true length. In practice, many solids are encountered in which either plane end surfaces are not parallel, or one or more end surfaces are curved; and hence projection drawings on principal planes will not show the true length of the circumferences of such surfaces.

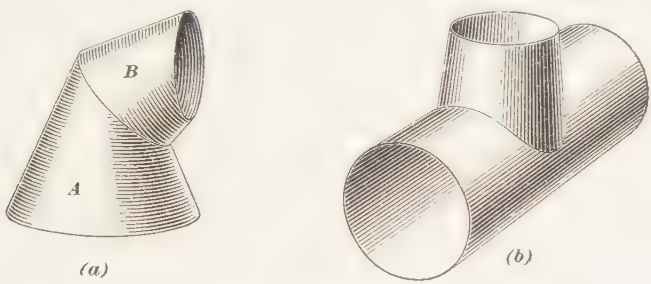


FIG. 56

Two cases in point are shown in Fig. 56; in (*a*) is shown a two-jointed tapering, or reducing, elbow, and in (*b*) a transition piece joined to a cylinder. Referring to Fig. 56 (*a*), it is readily seen that neither one of the two parts *A* and *B* of the elbow can be drawn in projection so that both ends will be parallel to a plane of projection. In this case a projection drawing is made so that one end surface is parallel to a plane of projection, and then a full view of the other end

is drawn; on this full view the circumference is divided as may be convenient, and the points of division for the triangles are projected to the several views, as shown in Fig. 57. When the projection of the inclined end of the cone, and also of its full view, are projected from evenly spaced elements, as was done in Fig. 57, the points on the circumference of the full view through which the projection lines pass are not equidistant. Thus, consulting the full view in Fig. 57, it is seen at once that the part *1′–2′* of the ellipse is smaller than the part *2′–3′*. Likewise, the part *2′–3′* is smaller than the part *3′–4′*.

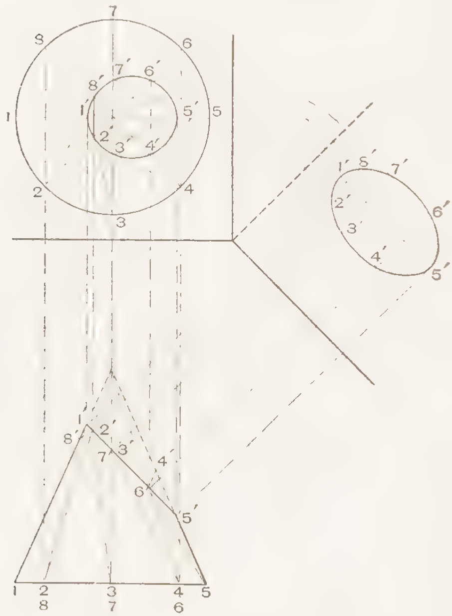
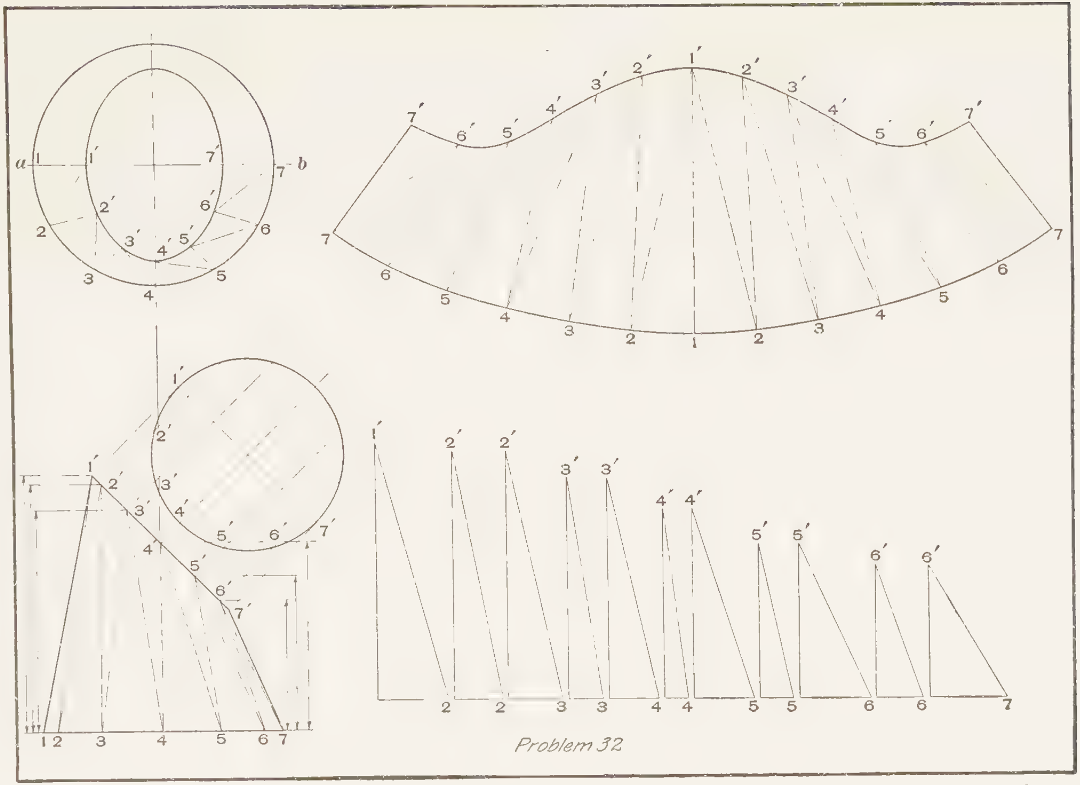


FIG. 57

For the purpose of developing the curved surface of the frustum, it is feasible to divide the full view of the inclined end into the same number of equal spaces as the full view of the base, shown in the horizontal view, and to draw triangles to suit these divisions. In practice, however, it is customary to make use of the same points and elements by which the full view of the inclined end was determined, in order to keep down the number of lines on the drawing. In making the development, care must then be exercised to find separately the correct length of each part of the ellipse constituting the full view, the parts being of unequal length, as just pointed out.

A reducing elbow of the form shown in Fig. 56 (*a*) is not necessarily composed of frustums of regular cones; for various reasons satisfactory to the designer the cross-sections



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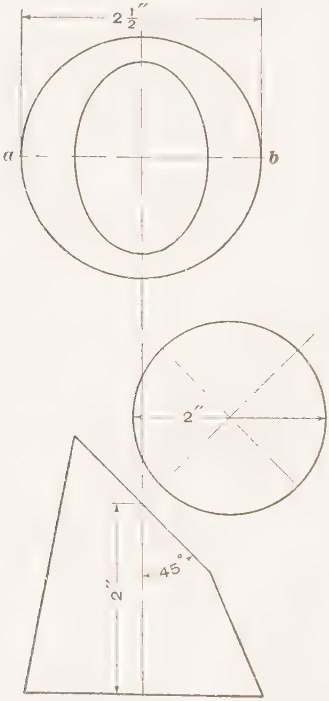
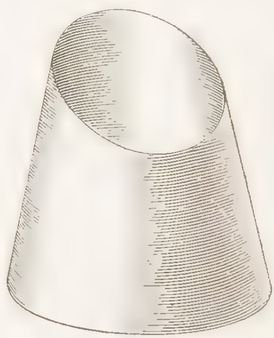
of the ends may have almost any shape. In such cases the projections of the joint between the parts *A* and *B* of Fig. 56 (*a*) must be drawn from the given full view. In practice, the full view would then be divided into a convenient number of equal spaces, equal in number to that into which the full view of the base is divided.

54. Problem 32. Sheet I.—Develop the curved surface of the transition piece of which projection drawings and a perspective view are shown in Fig. 58 (*a*) and (*b*). Observe that the transition piece is symmetrical in respect to the plane represented by the center line *a b*.

Solution. — Referring to the reduced copy of Sheet I, Exercise VIII, draw the two projections of the transition piece, projecting the horizon-



(*a*)

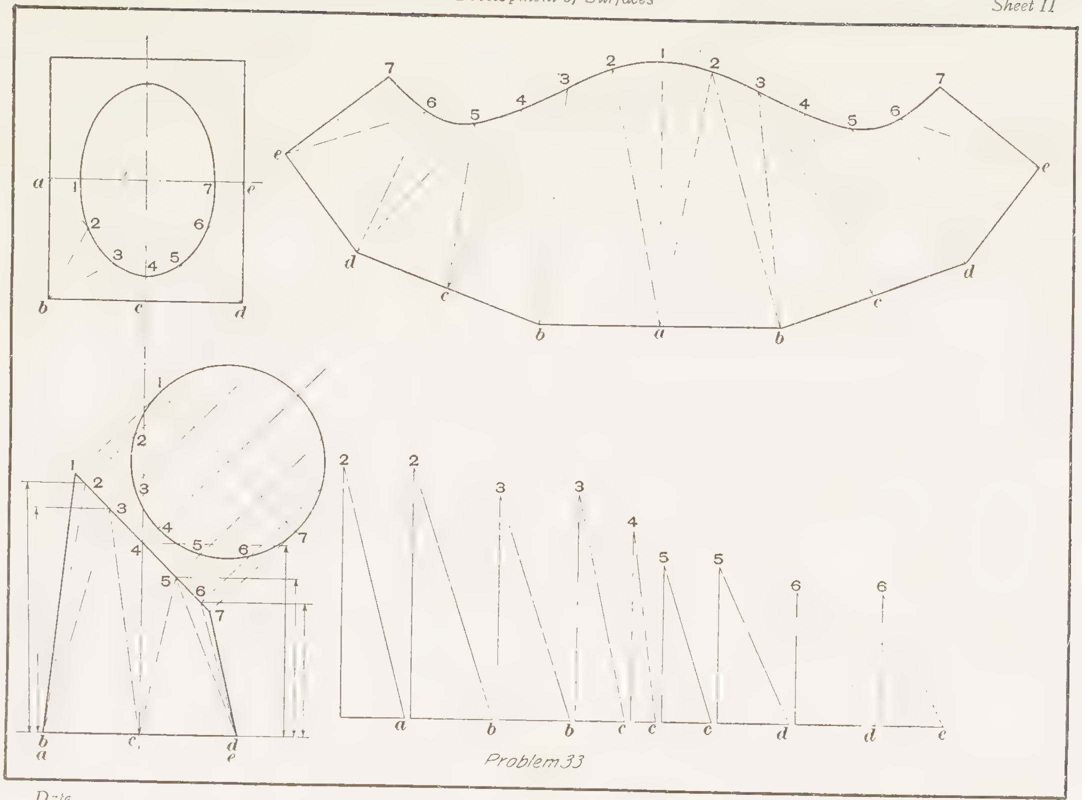


(*b*)

Fig. 58

tal view of the upper end from the full view. For projecting the horizontal view of the upper end, divide its full view into any convenient number of equal parts, say twelve. The center of the horizontal view may be located $1\frac{5}{8}$ inches from the upper border line and $1\frac{1}{2}$ inches from the left border line. The front projection of the base may

Exercise VIII | Development of Surfaces | Sheet II



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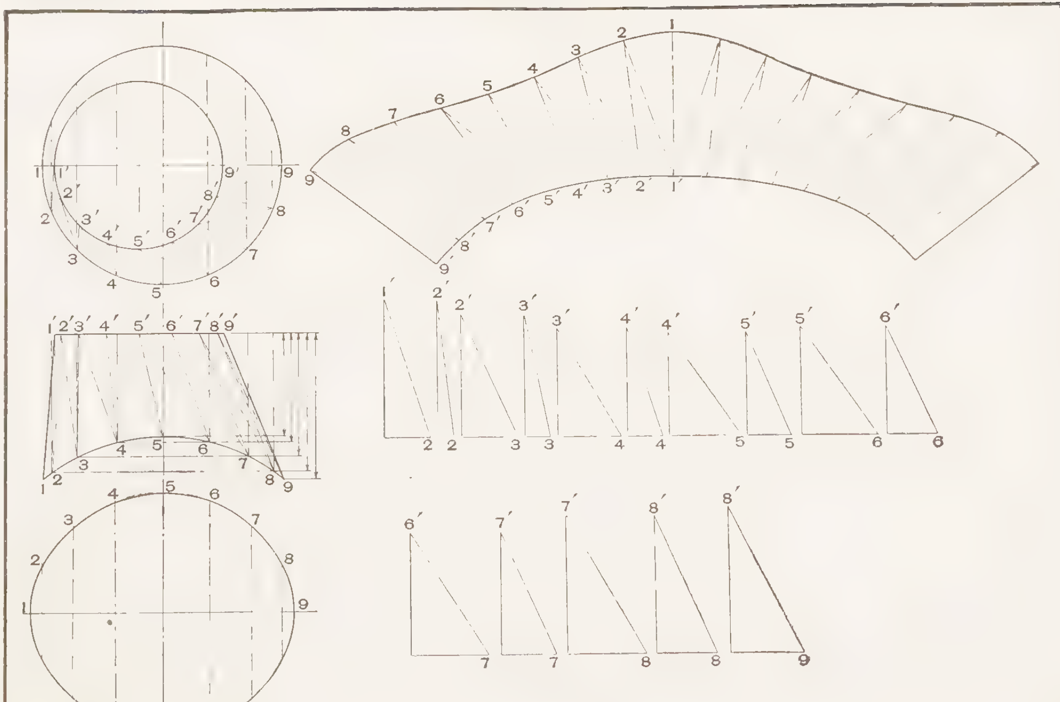
Exercise VIII — Development of Surfaces — Sheet III



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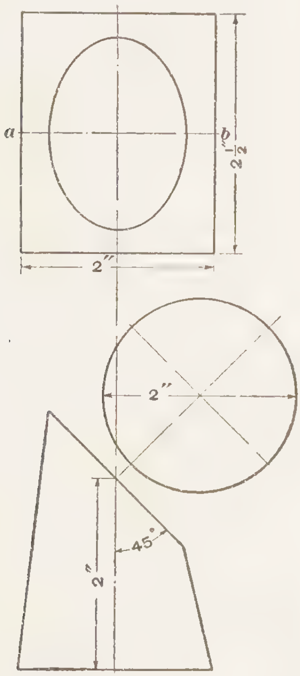
be drawn ½ inch from the lower border line. Divide the horizontal view of the base into the same number of equal parts as the full view of the upper end. On one side of the center line *a b* draw the horizontal projections of triangles to the points of division; also project and draw the front projection of the triangles. By triangulation determine the true length of the lines *1′–2*, *2–2′*, etc., noting that the lines *1–1′* and *7–7′* show in their true length in the front view, since they are parallel with the front plane. Observing that the length of the sides *1–2*, *2–3*, etc. of the triangles *1–2–1′*, *2–3–2′*, etc. is taken from the horizontal view, and that the length of the sides *1′–2′*, *2′–3′*, etc. of the triangles *1′–2–2′*, *2′–3–3′*, etc. is taken from the full view, that the sides *1–2*, *2–3*, etc. are equal, and that the sides *1′–2′*, *2′–3′*, etc. are equal, the pattern can be developed without further instruction.



(*a*)

(*b*)

Fig. 59

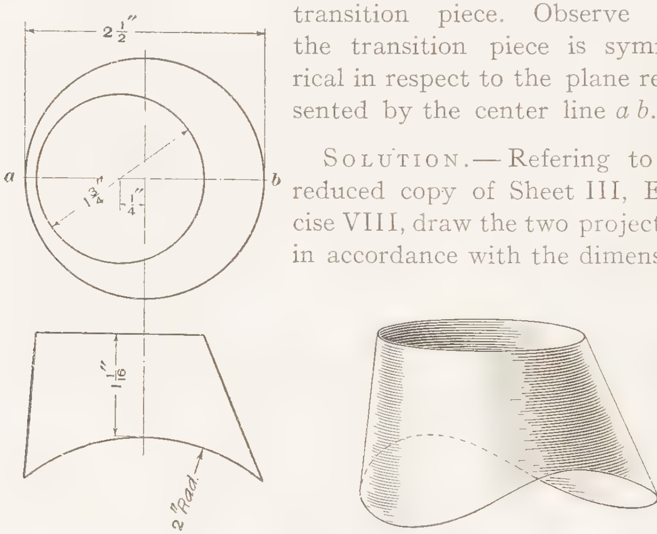
55. Problem 33. Sheet II.—Develop the transition piece having a rectangular base and a circular upper end of which projection drawings and a perspective view are shown in Fig. 59 (*a*) and (*b*). Observe that the transition piece is

symmetrical in respect to the plane represented by the center line $a\,b$.

The center of the horizontal view may be located $1\frac{3}{4}$ inches from the upper border line and $1\frac{3}{8}$ inches from the left border line; the front projection of the base may be located $\frac{1}{2}$ inch from the lower border line.

56. Problem 34. Sheet III.—An eccentric transition piece having a circular upper end and a base of which the horizontal projection is circular, as shown in Fig. 60 (*a*) and (*b*), joins a circular pipe. Develop the curved surface of the transition piece. Observe that the transition piece is symmetrical in respect to the plane represented by the center line $a\,b$.

Solution.—Refering to the reduced copy of Sheet III, Exercise VIII, draw the two projections in accordance with the dimensions

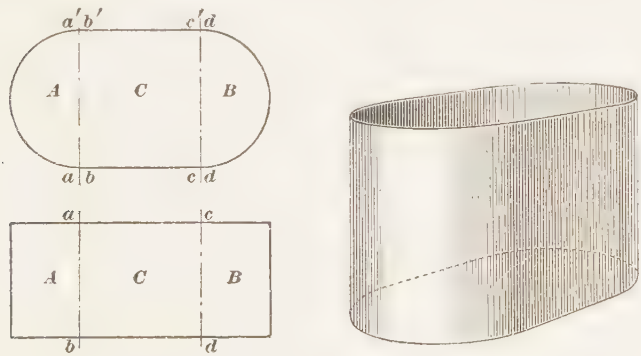


(*a*) Fig. 60 (*b*)

given in Fig. 60, locating the center of the horizontal projection of the base $1\frac{5}{8}$ inches from the upper border line and $1\frac{5}{8}$ inches from the left border line. Divide one of the symmetrical halves of the horizontal projection of the upper end and base into the same number of equal parts, say eight; project the points of division to the front view, and draw the horizontal and front projections of the triangles *1–1′–2*, *2–2′–3*, etc. Next develop the curved base either by triangulation or by parallel lines, the latter being

more convenient in this case; these lines should be passed through the points of division *2*, *3*, etc. The stretchout for the base is obviously the length of the arc *1* to *9* in the front view. Complete the development of the base by tracing a curve through the points laid off on the edge lines; the correct lengths of the arcs *1–2*, *2–3*, etc. of the horizontal view are given on the developed base.

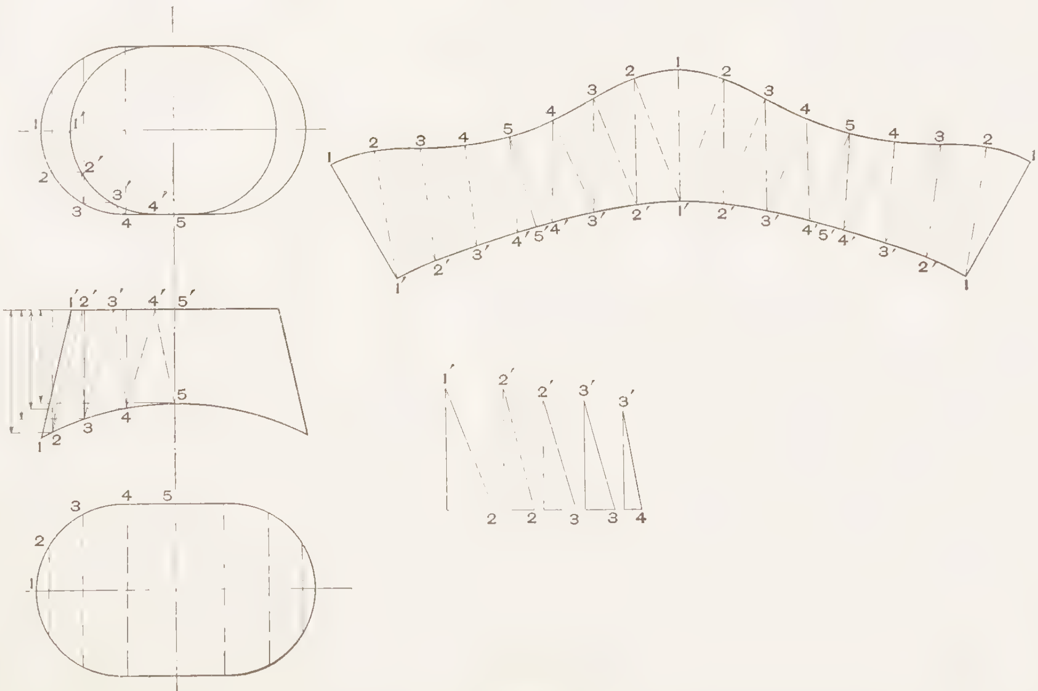
Find by triangulation the correct length of the lines *1′–2*, *2′–2*, etc., noting that the lines *1–1′* and *9–9′* show in the front view in their true length. With the correct lengths of the arcs *1–2*, *2–3*, etc. (which are unequal), taken from the developed base, and the correct lengths of the arcs *1′–2′*,



(*a*) Fig. 61 (*b*)

2′–3′, etc. (which are equal), taken from the horizontal view, the pattern can be developed and completed without further instruction.

57. When the surface of a solid that is to be developed is composed of plane and curved surfaces, the junctions of such surfaces must be taken as edge lines for the development. Thus, in the solid shown in Fig. 61 (*a*) and (*b*), which is composed of two semicylinders *A* and *B*, and a rectangular prism *C*, the junctions *a b*, *c d*, *a′ b′*, and *c′ d′* of the curved surfaces *a a′ b′ b* and *c c′ d′ d* with the flat surfaces *a b c d* and *a′ b′ c′ d′* are taken as edge lines. The reason for this is that in forming the article the bending for the curved sur-



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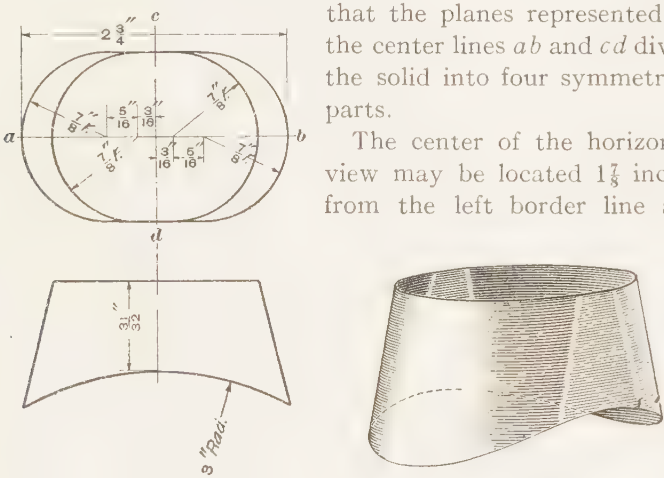
faces begins at the junctions, and consequently these lines are needed on the pattern to show the workman where to begin the bending operation.

58. PROBLEM 35. Sheet IV.—Develop the curved surface of the transition piece of which projection drawings and a perspective view are shown in Fig. 62 (*a*) and (*b*). Observe that the planes represented by the center lines *ab* and *cd* divide the solid into four symmetrical parts.

The center of the horizontal view may be located $1\frac{7}{8}$ inches from the left border line and



(*a*) FIG. 62 (*b*)

$1\frac{5}{8}$ inches from the upper border line; the front projection of the top may be drawn $3\frac{1}{2}$ inches from the upper border line.

Observe that, if for the purpose of development the horizontal projection of the curved base is divided into equal parts, the corresponding points of division on the circumference of the developed base will be unequally spaced.

DEVELOPMENT OF SPHERE

DEVELOPMENT BY ZONES

59. A sphere is one of the many solids that cannot be accurately developed by any method. In practice, results sufficiently accurate for most purposes are produced by two methods.

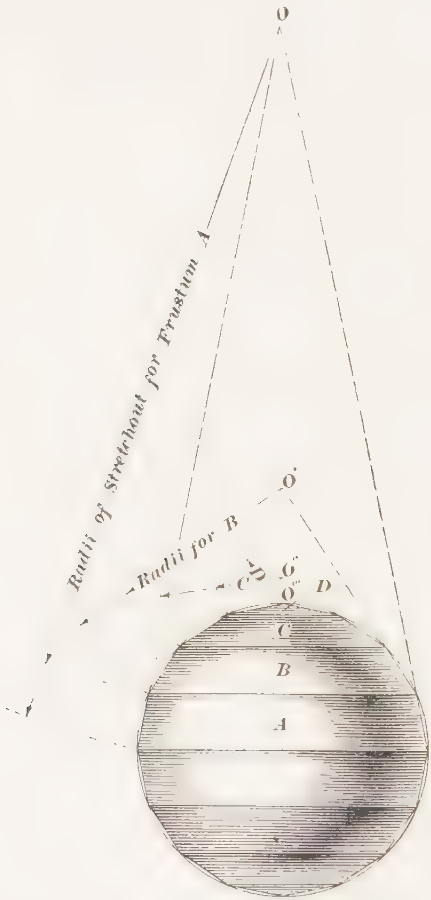


Fig. 63

In the method illustrated in Fig. 63 the sphere is divided by cutting planes into a number of zones, as *A*, *B*, *C*, and *D*, and each of these zones is considered as the frustum of a cone. Knowing the height of each frustum and its large and small diameter, the vertex of the cone of which it forms a part is easily found. Each frustum is developed by radial lines.

If the sphere is built up from patterns developed as frustums of cones, its appearance will be as in Fig. 63; if a closer approximation to the correct form is desired, the low part of each zone must be raised by stretching the metal by hammering.

DEVELOPMENT BY GORES

60. In the method of developing a sphere that is shown in Fig. 64 the sphere is divided into wedge-shaped pieces, called **gores,** by passing a number of cutting planes through its center; hence the method is spoken of as development by gores. Opposite gores, which lie between the same pair of cutting planes, as the gores *A*, *A* in the figure, are considered to be part of the curved surface of a cylinder. The curved

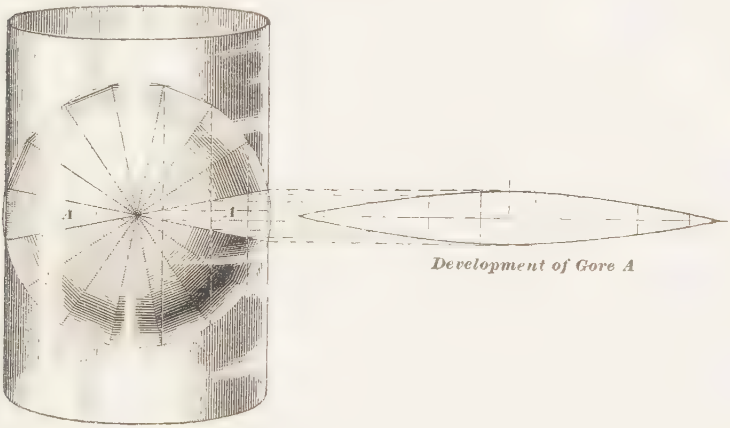


FIG. 64

surface of the gores is then developed in the same manner as the curved surface of a cylinder, that is, as a usual rule, by parallel lines. In practice, the sphere is divided into equal gores, so that it is necessary to develop but one.

As in the case of development by zones, the method of development by gores gives only an approximation to the spherical shape and raising of the metal must be resorted to if a closer approximation is desired.

INDEX

NOTE.—In this Volume, each Section is complete in itself and has a number. This number is printed at the top of every page of the Section in the headline opposite the page number, and to distinguish the Section number from the page number, the Section number is preceded by a section mark (§). In order to find a reference, glance along the inside edges of the headlines until the desired Section number is found, then along the page numbers of that Section until the desired page is found. Thus, to find the reference "Abaft, §15, p4," turn to the Section marked §15, then to page 4 of that Section.

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